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Should the U.S. Federal Government Significantly Increase the Exploration and/or Development of Space Beyond the Earth's Mesosphere?

Intercollegiate Debate Topic
1984-1985

Pursuant to Public Law 88-246

Compiled by the Congressional Research Service
Library of Congress

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II

PUBLIC LAW 88-246, 88TH CONGRESS, S. 2311,
DECEMBER 30, 1963

AN ACT To provide for the preparation and printing of compilation of materials relating to annual national high school and college debate topics.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Librarian of Congress is authorized and directed to prepare compilations of pertinent excerpts, bibliographical references, and other appropriate materials relating to (1) the subject selected annually by the National University Extension Association as the national high school debate topics and (2) the subject selected annually by the American Speech Association as the national college debate topic. In preparing such compilations the Librarian shall include materials which in his judgment are representative of, and give equal emphasis to, the opposing points of view on the respective topics.

Sec. 2. The compilations on the high school debate topics shall be printed as Senate documents and the compilations on the college debate topics shall be printed as House documents, the cost of which shall be charged to the congressional allotment for printing and binding. Additional copies of such documents may be printed in such quantities and distributed in such manner as the Joint Committee on Printing directs.

Approved December 30, 1963.

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FOREWORD

The 1984-1985 intercollegiate debate topic is "Resolved: that the U.S. Federal Government should significantly increase the exploration and/or development of space beyond the Earth's mesosphere."

In compliance with Public Law 88-246, the Congressional Research Service of the Library of Congress prepared this compilation of materials and bibliographic references to assist collegiate debaters in researching this year's topic. The excerpts from books, periodicals, and other documents were selected to provide background information, an overview of the principal issues, and a balance of opposing views. We also included some materials that are not readily available in public or research libraries. Bibliographic references were also chosen to provide a wide range of information and opinions. In selecting items for this reader and bibliography, the Congressional Research Service (CRS) has attempted to sample the wide spectrum of opinions reflected in current literature on these questions. No preference for any policy is indicated by the selection or positioning of articles herein, nor should one infer CRS disapproval of any policy or article not included.

The selected items have been arranged in five sections: history and overview; space law; space exploration and development, including space policy and economic aspects, technology, industrialization, space station, living in space, planetary exploration, and foreign space programs; militarization of space; and resource allocation among competing national priorities. By agreement with the Project Coordinator for the Committee on Intercollegiate Debate and Discussion of the Speech Convention of America, this document does not take into account questions of specific alternative uses of the current or proposed Federal funds devoted to U.S. space programs and the effect that such alternatives might have upon the scope, direction, or viability of the U.S. space program.

U.S. Government documents listed in the bibliography may be found in most U.S. Government depository libraries which can be identified by your local public library. The Library of Congress cannot distribute copies of these or other materials to the debaters.

Information is included at the end of this volume on guides to additional resources and other publications and associations that may be useful in expanding and updating this compilation. Finally, there is included a list of relevant publications that are available for purchase from the Superintendent of Documents, Government Printing Office.

B. F. Mangan, Senior Bibliographer in Science, Library Services Division, and Marcia Smith, Specialist in Aerospace and Telecommunications Systems, Science Policy Research Division, selected the items included in this reader. In addition, they compiled the bibliography, and Ms. Mangan prepared the guide to additional research sources. Dagnija Sterste-Perkins, Foreign Affairs and National Defense Division, and others offered assistance and suggestions on subtopics of the debate issue. Sherry Shapiro, Library Services Division, coordinated the preparation of this debate manual for publication. Ann Eschete secured copyright permissions, and with Lisa Barker and C. Lee Burwasser assembled and prepared items for publication. John White and Barbara Hall provided the secretarial production of the bibliography and research guide.

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Good luck to each debater in researching, preparing, and presenting arguments on this year's topic.

Gilbert Gude
Director, Congressional Research Service

56 ¶ The President's News Conference of *March* 26, 1958.

THE PRESIDENT. Good morning. Please sit down.

In the scientific field, I have two or three announcements, the first of which I will read, although the document will be in mimeographed form and you can get it after you leave here. This one has to do with forthcoming tests.

[*Reading*] In line with what I said to the press on July 3, 1957, the United States will demonstrate the progress our scientists are achieving in reducing radio-active fallout from nuclear explosions.

To this end, for the first time at any test, we are planning to invite the United Nations to select a group of qualified scientific observers to witness at the Pacific Proving Ground this summer a large nuclear explosion in which radio-active fallout will be drastically reduced.

We will also invite—as we have on occasions in the past—a representative group of United States and foreign news media correspondents.

The United States scientists have been making progress in reducing radio-active fallout from nuclear explosions in the hope and belief that basic advances in both the peaceful and military uses of nuclear energy will thus be achieved. The advantages to mankind of continued progress in this field are obvious.

The United States has always publicly announced in advance its

Reproduced from Public Papers of the Presidents of the United States: Dwight D. Eisenhower, 1958. Washington, G.P.O., 1958. p. 232-242.

nuclear testing programs. We trust that the forthcoming tests will provide valuable information to the world. [*Ends reading*]

Now, the next statement is about another document. There has been prepared by my Scientific Advisory Committee a paper that is called, "Introduction to Outer Space." [1] This report, in my opinion, is the most interesting and fascinating thing in this field that I have seen, and I want to make it available to the entire public. Frankly, I am hopeful that all publicity media will find it so interesting that they will give it the widest possible dissemination.

Then, I wanted to make this final statement: I expect to send up shortly recommended legislation providing for civilian control and direction of governmental activities incident to civilian space programs.

As I say, that report will be—is that to be this afternoon or this morning? [*Confers with Mr. Hagerty*] That one you will get this afternoon.

The first one that I read is the one you will get this morning; the other one will be ready this afternoon.

That's all.

Q. Marvin L. Arrowsmith, Associated Press: Mr. President, can you say specifically whether Russia and other Communist nation observers will attend those tests?

THE PRESIDENT. Of course I can't tell what they will accept, but we are hopeful that the United Nations will designate the Scientific Committee for Detection, I believe it is, of Radioactivity—that's about its name. On that committee are U. S. S. R., Czechoslovakia, the United States, U. K., Canada, and a few others. As a matter of fact, Mr. Hagerty can give you also the entire list of nations. [*Confers with Mr. Hagerty.*]

Mr. Hagerty wants me to read the full—the United Nations Scientific Committee on the Effects of Atomic Radiation, that's the name of the committee.

Q. Peter Lisagor, Chicago Daily News: Mr. President, Mr. Khrushchev has in recent weeks hinted that Russia might unilaterally end its atomic tests and stop production of nuclear weapons. My question is: does the administration have any information that this is a real possibility, and how would you view such a Soviet move?

THE PRESIDENT. Well, of course, anything is a possibility. As we have been reporting from time to time, they have undergone a long series of

[1] See Item 57.

tests and I don't know what they will do, of course.

So far as we are concerned, we have been perfectly honest in stating exactly what we expect to do. It has been many months ago that we announced our spring tests; and we have always stated that when there was any reliable agreement for stopping tests, and particularly when this can be connected with elimination of manufacture for weapon purposes, that we would be quite ready to go with the thing.

I don't know anything about the possibility of their making a statement.

Q. John R. Gibson, Wall Street Journal: Mr. President, there has been considerable discussion recently of taxes. Could you say just what the administration's policy is on tax cuts now, particularly as to timing?

THE PRESIDENT. Well, sir, I have tried to be very accurate in what I had to say about it. I have never excluded the possibility that there might come a situation where a tax reduction would seem desirable.

At the same time, I think that every thoughtful person, certainly that I have met and this includes leaders from both parties, views this step or possible step with such seriousness that they are not going to be stampeded into doing it. As a matter of fact, I believe the Secretary of the Treasury has conferred with leaders in the Democratic Party, with the result that we have agreed to do nothing except with bipartisan consultation, at least notification of intention.

All sorts of difficulties arise with the possibility of tax reduction. Most of you have been aware of some of the anxiety voiced by our people for larger and larger military appropriations. Those appropriations by '59 will be very considerably greater than they are now.

There have been all sorts of other proposals for expenditures that will swell national budgets if all of them are approved.

So, in any event, there seems to be the prospect of very greatly increased expenditures.

Now, if you recognize that any tax cut is bound to increase the gap between revenues and expenditures, realizing again the seriousness of large and continuing deficits upon our whole fiscal and financial system, then you will see that this is not something to do lightly.

I do say that we are watching every development as closely as we know how. We try to get advice, information, counsel from every phase of our American life, and we are certainly going to do those things we think

should be done; but we are not going into a tax cut or any other what we believe to be unwise program that can hurt us badly in the future. We have got to think of the years to come as well as the immediate month in which we are living.

Q. Chalmers M. Roberts, Washington Post: Mr. President, to go back to the nuclear testing for a moment: have you had the report from Dr. Killian on the feasibility of test detection if there were an agreement?

THE PRESIDENT. I didn't understand the question correctly—feasibility?

Q. Mr. Roberts: Have you had a report from Dr. Killian on the feasibility of detecting tests in the Soviet Union if there were an agreement, and do your earlier remarks indicate that there is no truth in the reports that you might consider separating the test ban from the production cutoff?

THE PRESIDENT. Mr. Roberts, as I have told you time and again, certainly I believe it would be unwise to take a perfectly rigid position in respect to any of these things where any agreement would seem to be a reliable one, and would seem to be opening the door to wider and better negotiations with the Soviet Union.

Now, I have not only had many conferences with Dr. Killian, but with others in the scientific world about the feasibility of detecting tests.

While I think there is certainly a little field for uncertainty, and some differing opinion, I think that by and large for any sizable test of any kind, if it didn't go way down into the, you might say, fractional kiloton, that the tests ought with proper inspectional facilities, seismic and electronic, and so on, that they ought to be detected.

Q. Robert C. Pierpoint, CBS News: Mr. President, in view of the long exchange of messages that you have had with the Soviet Union, and particularly the most recent message from the U. S. S. R., do you believe that Summit talks are closer or further away?

THE PRESIDENT. Well, that is a very difficult guess to make, you might say.

This is what I am trying to do: I am trying to maintain a position that I think is conciliatory, that will reflect reasonableness and logic and truth as we see it.

Now, we simply, as I see it, must not by going to a Summit meeting appear to accept every contention that the Soviets are now making. In other words, we must not tacitly say "Yes, we approve of everything that

they are now saying as possible subjects for conversation." It isn't necessarily true or acceptable to us. As I say again, we must be careful to prepare these meetings properly.

Q. Mrs. May Craig, Portland (Maine) Press Herald: Mr. President, although there is plenty of food in this country, many families, especially children and most especially the unemployed, cannot buy because the prices are so high. Have you ever considered the so-called Brannan plan by which the food stuffs went into the market and at whatever price it would bring and the Government pays the farmer the difference between that and parity?

THE PRESIDENT. Well, Mrs. Craig, yes, I have read it often, read about it, discussed it, and frankly I do not believe in the Brannan plan.

Now, I do say this: with our surpluses, I believe that we could find better ways at times such as these of using our surpluses better. And we are doing this more generously and more freely at this moment. But I just don't believe that you can get such a program as this, and work it in our country and keep farmers free.

Q. Joseph R. Slevin, New York Herald Tribune: Mr. President, do you see any sign of the downward movement of the economy as coming to an end?

THE PRESIDENT. Well, I think there are many factors that would imply that the bottom is certainly close, or possibly even now reached. But we have gone through these factors, about the strength of consumer buying and many things of that kind. I don't see any need this morning for going through all of them. My own feeling is we are going through the worst of it right now.

Q. Kenneth M. Scheibel, Gannett Newspapers: Mr. President, getting back to the farm situation, there are reports that you will veto the farm price freeze measure and then in an administrative action, announce some increase in the supports for crops and for dairy products as you did in 1956. Could you tell us anything about that?

THE PRESIDENT. Well, I am always intrigued by prophecies of what I shall do and how I shall do it.

Now, the bill that we have now is still under study. I've had many conferences with my people, and action will be taken soon.

Q. Sarah McClendon, El Paso Times: Mr. President, back to this food question. There are people out in New Mexico right now who can't even get beans because they can't get them out of surplus food

stocks. They are going hungry. There are some unemployed in this country who can't get anything but starches to eat, and that has been going on for months. Can't we do something to give better distribution of surplus foods or to get meat into the surplus pile so that we can give these people a balanced diet?

THE PRESIDENT. Well, right now, if you can take beef at over 30 cents and pork, over 20, and call it surplus, you'll be doing something. I don't see how you can do it. I don't see how meat can be in surplus.

Now, as to methods that there may be for feeding the hungry, after all, one of the things that I am attempting to do by this extension of the benefits of unemployment insurance is to take the burden off the States for what they have to do in assistance within the States and, therefore, give them more opportunity to take care of people that are not taken care of by an extension of this kind. I believe—did I sign that this morning? [*Confers with Mr. Hagerty*] I believe it is either down today, or on the route.

But I agree with you, something should be done for people that are hungry, but we must not just always say that it has got to be right square here from Washington, that we are going to send this and that. We must do our part, respecting the responsibilities, the rights of the States, and if we do our things in that formula, I think we won't go too badly wrong.

Q. Edward P. Morgan, American Broadcasting Company: Another domestic matter, Mr. President. Little Rock is still unsolved. There are responsible reports indicating indeed that the basic issues are more embittered and in a worse state of ferment than they have been before.

Your Civil Rights Commission exists but it hasn't really got its work off the ground and hasn't really got a budget of its own.

Do such things indicate an inclination on the part of the administration to follow rather than lead these civil rights problems to a decision; or, on the other hand, do you have in mind some intensification of pressure on the part of the Federal Government toward them?

THE PRESIDENT. Well, now, just a minute. Intensification of Federal activity can mean many things, and certainly I would have to know exactly what you were proposing before I would believe it to be legal and proper and desirable.

Now I have preached, since the day I came to this office, and long

before, that we are going to solve some of these great internal social problems of the United States of America by reason, by education, by tolerance of the other fellow's views.

I do not believe that all of these problems can be solved just by a new law, or something that someone says, with teeth in it. For example, when we got into the Little Rock thing, it was not my province to talk about segregation or desegregation. I had the job of supporting a Federal court that had issued a proper order under the Constitution, and where compliance was prevented by action that was unlawful.

I had to do that, and that is an entirely different thing from me starting out new laws for attacking this basic problem, which I again say is not going to be solved finally until it is done by understanding and reason.

Now, on the other hand, with respect to your reference to the Commission, surely it has had a hard time getting off the ground. We had to give it, you might say, a loaned budget, but I have great hopes for what it will do in both these fields, watching and seeing what are the legal difficulties that occur, as well as what can be done in helping to get things done in what you might call the educational and even, indeed, the spiritual field.

Q. Frank van der Linden, Nashville Banner: Sir, Senator McClellan's investigating committee has just come out with their report criticizing the Teamsters' Union and a few others on the grounds of alleged corruption, and proposing several laws to promote union democracy through secret ballots, and so forth. Is it your hope that Congress will pass some legislation along those lines before it goes home this year? I know you recommended——

THE PRESIDENT. I have a very fine answer for you. If you will just read again exactly what I said in my special message, I think it was in late January, on labor, you will find exactly what my views are.

Q. John Scali, Associated Press: Mr. President, recently you told us, sir, that you would be willing to hold a Summit conference in the United States if you thought it would contribute to peace. Since then there have been reports that the administration felt that Geneva might be a better site, particularly in view of the feeling that Mr. Khrushchev might use a visit to the United States for his own propaganda purposes. Could you tell us what your latest view on this is, sir?

THE PRESIDENT. I have no change in the views that I have already

expressed, but I will tell you this: by no means do I fear the results on America of a visit by Mr. Khrushchev.

Q. Richard L. Wilson, Cowles Publications: Mr. President, some of your critics claim that you are not doing enough to combat the recession, that to wait until the middle of April is too late.

I wonder if you could discuss that point?

THE PRESIDENT. I think I explained it rather thoroughly in connection with my remarks on tax reduction. I think that we have got to be very, very careful of what we are doing to this economy over the years as well as just looking at the immediate difficulties in which we find ourselves; to fail to do so, to my mind, is merely to bring on again a difficulty that could be even worse. We can compound difficulties here. So, I can run through again for you all the things that we have put down on paper, the recommendations I made to the Congress. They are numerous, and I think mostly they are reasonable, but I do believe that if we go frantic on this, like some people wanted to do on Sputnik, we can be doing the wrong thing.

Q. Raymond P. Brandt, St. Louis Post-Dispatch: Have you and your advisers projected the spending of this Congress so that you can make an estimate on the deficit for the current fiscal year and next year?

THE PRESIDENT. Well, I'll tell you, we tried a little bit, but you can't do it. For example, the housing bill now before me was first started off at $2.9 billion; and now we have got one item in the housing bill, $1.5 [billion] that means, as far as I can see, just right square out of the Treasury as quick as they come in and recommend that the Government purchase these insured loans. So you just can't tell what is going to happen until we are further along in the session I think, as far as the amounts are concerned. But I do think this: it would be futile to believe we could keep the amounts down to what they are now.

Q. Rod MacLeish, Westinghouse Broadcasting Company: Mr. President, going back to the Summit conference for a moment, sir, Mr. Pierpoint commented on the long exchange of letters between you and Premier Bulganin. The Russians seem prompted by some sense of immediate urgency to have a Summit conference, more than usual. Have you any comment on what might be giving them this sense of urgency?

THE PRESIDENT. Well, I really believe it is their hoped for effect upon the world at large. By saying these things, by seeing in the papers

what they purport to mean, they believe they are getting the world convinced that Russia really wants peace and negotiated agreements that are sound and practical and fair to both sides and enforceable.

Now, that is what they, it seems to me, are trying to get over. Now, when you take ourselves, and we try to analyze these things—remember, we are handicapped by the attempt at least to observe fact and truth—why sometimes our answers may not seem as convincing; and if they think they are getting a propaganda advantage, there it is.

Q. Dayton Moore, United Press: Mr. President, there are reports that many people are holding off from buying automobiles to wait and see whether there is a cut in the excise tax. If there should be such a cut, do you think it should be retroactive?

THE PRESIDENT. Well, I'm not going to answer that question directly for the simple reason I don't want yet to discuss the details of any such proposal before you until I believe that necessity is here.

But I will say this: I believe that the American public now should be buying on the basis of the worth of the product that is offered to them. I believe that there is a great field for expansion of business by better salesmanship on the part of business concerns. I believe we have got great savings, I believe that we have got to offer things in a better packaged way, we've got to do better advertising; and above all things let the public buy when they think they are getting a bargain and not worrying about what is going to be some possible future action.

Q. John Herling, Editors Syndicate: Mr. President, this has to do with the reciprocal trade agreement. As you know, sir, many Senators and Congressmen are concerned about the possible adverse effects on their communities of the renewal of the reciprocal trade agreement legislation in general. However, many of them believe they could vote for the renewal of such an important measure if there were less stress and strain and less opposition back home, if an amendment were added in the form of a trade adjustment act, which would aid labor and industry and communities generally which might be adversely affected by the operations of the reciprocal trade agreements legislation.

Is there any prospect that you and the administration would support such an amendment of the reciprocal trade act?

THE PRESIDENT. Well, the only amendment I can think would be more useful was that you could go back to 50 percent above the 1934

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tariff levels in order to protect a particular industry when there was clear evidence that it was being threatened.

Now, I don't know of any other amendment that we have thought of, and I don't know what you could be thinking of.

Q. Mr. Herling: Well, sir, aside from the peril point angle, there is legislation introduced which would physically and economically aid communities that might be adversely affected.

THE PRESIDENT. Oh, you mean direct, some kind——

Q. Mr. Herling: Direct subsidy, yes.

THE PRESIDENT. Well, whatever you can——

Q. Mr. Herling: The Randall Commission report, for example.

THE PRESIDENT. Well, there, of course, there have been all sorts of things suggested even to the degree of assisting a small industry that wants to go into something else, and giving it Federal help while it gets going on something that's more profitable for it, and all sorts of things. None of them as far as I know have been written into legislation, but there is, of course, all of this concern about the so-called depressed areas by giving greater intensity to your procurement efforts in those areas, wherever you can. Everything of that kind has been done that I know of, but the idea you are now propounding, I don't——

Q. Mr. Herling: If specific legislation were laid out, would you consider it?

THE PRESIDENT. I would have to take a look at it.

Q. William V. Shannon, New York Post: Mr. President, I want to clear up something at the last press conference.

You said that you didn't recall that Mr. Dulles had used the word "fraud" in describing the Russian conference proposal. In checking the transcript, it shows that he did definitely use both the words "fraud" and "hoax," and my question is: are you still convinced that there is no difference between yourself and Mr. Dulles in your attitude on this question?

THE PRESIDENT. Well, I would say that Secretary Dulles and I confer by telephone or personally at least 5 to 6 hours a week, more than that if you would count both Cabinet and National Security Council.

Before he made his statement yesterday morning, we talked for, starting the afternoon before and for the morning, another considerable period. I wouldn't guess its length.

Now, if there are any great differences between Secretary Dulles and

myself, I am unaware of them. I have told you time and again I believe he is the most informed and wisest man in the field of international relations that I know, and I certainly have no great differences with him.

Q. Donald H. Shannon, Los Angeles Times: Mr. President, this is an area where you are being accused of doing too much, if you did it.

There are in circulation in Pennsylvania now badges bearing your picture and a ribbon attached to the badge that says: "I like Stassen for Governor."

Did you authorize this, and, if it was not authorized, what do you think of it? [*Laughter*]

THE PRESIDENT. Did you say you have seen that or did you just——

Q. Mr. Shannon: Yes, sir; I have seen the picture; there is one in this room.

THE PRESIDENT. The only thing I can say is this: I have always refused in advance of any primary or of any selection of Republican candidate for any office to intervene in any way, and I wouldn't want to be used either directly or indirectly in such a campaign.

Marvin L. Arrowsmith, Associated Press: Thank you, Mr. President.

NOTE: President Eisenhower's one hundred and twenty-ninth news conference was held in the Executive Office Building from 10:28 to 10:58 o'clock on Wednesday morning, March 26, 1958. In attendance: 234.

73 Statement About the Future of the United States Space Program. *March 7, 1970*

OVER the last decade, the principal goal of our Nation's space program has been the moon. By the end of that decade men from our planet had traveled to the moon on four occasions and twice they had walked on its surface. With these unforgettable experiences, we have gained a new perspective of ourselves and our world.

I believe these accomplishments should help us gain a new perspective of our space program as well. Having completed that long stride into the future which has been our objective for the past decade, we must now define new goals which make sense for the seventies. We must build on the successes of the past, always reaching out for new achievements. But we must also recognize that many critical problems here on this planet make high priority demands on our attention and our resources. By no means should we allow our space program to stagnate. But—with the entire future and the entire universe before us—we should not try to do everything at once. Our approach to space must continue to be bold—but it must also be balanced.

When this administration came into office, there were no clear, comprehensive plans for our space program after the first Apollo landing. To help remedy this situation, I established in February of 1969 a space task group, headed by the Vice President, to study possibilities for the future of that program. Their report was presented to me in September. After reviewing that report and considering our national priorities, I have reached a number of conclusions concerning the future pace and direction of the Nation's space efforts. The budget recommendations which I have sent to the Congress for fiscal year 1971 are based on these conclusions.

Three General Purposes

In my judgment, three general purposes should guide our space program.

One purpose is exploration. From time immemorial, man has insisted on venturing into the unknown despite his inability to predict precisely the value of any given exploration. He has been willing to take risks, willing to be surprised, willing to adapt to new experiences. Man has come to feel that such quests are worthwhile in and of themselves—for they represent one way in which he expands his vision and expresses the human spirit. A great nation must always be an exploring nation if it wishes to remain great.

A second purpose of our space program is scientific knowledge—a greater systematic understanding about ourselves and our universe. With each of our space ventures, man's total information about nature has been dramatically expanded; the human race was able to learn more about the Moon and Mars in a few hours last summer than had been learned in all the centuries that had gone before. The people who perform this important work are not only those who walk in spacesuits while millions watch or those who launch powerful rockets in a burst of flame. Much of our scientific progress comes in laboratories and offices, where dedicated, inquiring men and women decipher new facts and add them to old ones in ways which reveal new truths. The abilities of

Reproduced from Public Papers of the Presidents of the United States: Richard Nixon, 1970. Washington, G.P.O., 1971. p. 250-253.

these scientists constitute one of our most valuable national resources. I believe that our space program should help these people in their work and should be attentive to their suggestions.

A third purpose of the United States space effort is that of practical application—turning the lessons we learn in space to the early benefit of life on earth. Examples of such lessons are manifold; they range from new medical insights to new methods of communication, from better weather forecasts to new management techniques and new ways of providing energy. But these lessons will not apply themselves; we must make a concerted effort to see that the results of our space research are used to the maximum advantage of the human community.

A Continuing Process

We must see our space effort, then, not only as an adventure of today but also as an investment in tomorrow. We did not go to the moon merely for the sport of it. To be sure, those undertakings have provided an exciting adventure for all mankind and we are proud that it was our Nation that met this challenge. But the most important thing about man's first footsteps on the moon is what they promise for the future.

We must realize that space activities will be a part of our lives for the rest of time. We must think of them as part of a continuing process—one which will go on day in and day out, year in and year out—and not as a series of separate leaps, each requiring a massive concentration of energy and will and accomplished on a crash timetable. Our space program should not be planned in a rigid manner, decade by decade, but on a continuing flexible basis, one which takes into account our changing needs and our expanding knowledge.

We must also realize that space expenditures must take their proper place within a rigorous system of national priorities. What we do in space from here on in must become a normal and regular part of our national life and must therefore be planned in conjunction with all of the other undertakings which are also important to us. The space budget which I have sent to Congress for fiscal year 1971 is lower than the budget for fiscal year 1970, a condition which reflects the fiscal constraints under which we presently operate and the competing demands of other programs. I am confident, however, that the funding I have proposed will allow our space program to make steady and impressive progress.

Six Specific Objectives

With these general considerations in mind, I have concluded that our space program should work toward the following specific objectives:

1. We should continue to *explore the moon*. Future Apollo manned lunar landings will be spaced so as to maximize our scientific return from each mission, always providing, of course, for the safety of those who undertake these ventures. Our decisions about manned and unmanned lunar voyages beyond the Apollo program will be based on the results of these missions.

2. We should move ahead with bold *exploration of the planets and the universe*. In the next few years, scientific satellites of many types will be launched into earth orbit to bring us new information

about the universe, the solar system, and even our own planet. During the next decade, we will also launch unmanned spacecraft to all the planets of our solar system, including an unmanned vehicle which will be sent to land on Mars and to investigate its surface. In the late 1970's, the "Grand Tour" missions will study the mysterious outer planets of the solar system—Jupiter, Saturn, Uranus, Neptune, and Pluto. The positions of the planets at that time will give us a unique opportunity to launch missions which can visit several of them on a single flight of over 3 billion miles. Preparations for this program will begin in 1972.

There is one major but longer-range goal we should keep in mind as we proceed with our exploration of the planets. As a part of this program we will eventually send men to explore the planet Mars.

3. We should work to *reduce substantially the cost of space operations.* Our present rocket technology will provide a reliable launch capability for some time. But as we build for the longer-range future, we must devise less costly and less complicated ways of transporting payloads into space. Such a capability—designed so that it will be suitable for a wide range of scientific, defense, and commercial uses—can help us realize important economies in all aspects of our space program. We are currently examining in greater detail the feasibility of reusable space shuttles as one way of achieving this objective.

4. We should seek to *extend man's capability to live and work in space.* The Experimental Space Station (XSS)—a large orbiting workshop—will be an important part of this effort. We are now building such a station—using systems originally developed for the Apollo program—and plan to begin using it for operational missions in the next few years. We expect that men will be working in space for months at a time during the coming decade.

We have much to learn about what man can and cannot do in space. On the basis of our experience with the XSS, we will decide when and how to develop longer-lived space stations. Flexible, long-lived space station modules could provide a multipurpose space platform for the longer-range future and ultimately become a building block for manned interplanetary travel.

5. We should *hasten and expand the practical applications of space technology.* The development of earth resources satellites—platforms which can help in such varied tasks as surveying crops, locating mineral deposits, and measuring water resources—will enable us to assess our environment and use our resources more effectively. We should continue to pursue other applications of space-related technology in a wide variety of fields, including meteorology, communications, navigation, air traffic control, education, and national defense. The very act of reaching into space can help man improve the quality of life on earth.

6. We should *encourage greater international cooperation in space.* In my address to the United Nations last September, I indicated that the United States will take positive, concrete steps "toward internationalizing man's epic venture into space—an adventure that belongs not to one nation but to all mankind. I believe that both the adventures and the applications of space missions should be shared by all peoples. Our progress will be faster and our accomplishments will be greater if nations will join together in this effort,

both in contributing the resources and in enjoying the benefits. Unmanned scientific payloads from other nations already make use of our space launch capability on a cost-shared basis; we look forward to the day when these arrangements can be extended to larger applications satellites and astronaut crews. The Administrator of NASA recently met with the space authorities of Western Europe, Canada, Japan, and Australia in an effort to find ways in which we can cooperate more effectively in space.

It is important, I believe, that the space program of the United States meet these six objectives. A program which achieves these goals will be a balanced space program, one which will extend our capabilities and knowledge and one which will put our new learning to work for the immediate benefit of all people.

As we enter a new decade, we are conscious of the fact that man is also entering a new historic era. For the first time, he has reached beyond his planet; for the rest of time, we will think of ourselves as men *from* the planet earth. It is my hope that as we go forward with our space program, we can plan and work in a way which makes us proud *both* of the planet from which we come *and* of our ability to travel beyond it.

NOTE: The statement was released at Key Biscayne, Fla.

On the same day, the White House released the transcript of a news briefing about the United States space program by Dr. Thomas O. Paine, Administrator, National Aeronautics and Space Administration.

On March 15, 1970, the Office of Science and Technology released a report by the Space Science and Technology Panel of the President's Science Advisory Committee entitled "The Next Decade in Space" (Government Printing Office, 63 pp.). The report set out in detail the administration's space program as outlined in the President's statement.

264 ¶ Statement by the President on U.S. Achievements in Space. *August* 17, 1960

THE EVENTS of the past weeks have demonstrated beyond all doubt the vigor, capabilities and leadership of the United States in the conquest of the frontiers of science and technology and, in particular, in the exploration and utilization of space. The entire nation is proud of the impressive array of successful experiments carried out by the United States this year:

—Pioneer V, the sun satellite, which continued to receive and transmit radio messages over a period of three months and to a distance of 22,500,000 miles from earth;

—Tiros I, the meteorological satellite which took 23,000 cloud cover pictures during its operating life of three months and provided increased assurance that revolutionary improvements in the science of weather forecasting will be achieved;

—the success that has attended the efforts in the satellite-based navigation program called Transit I;

—the orbiting of Echo I, the 100-foot balloon which circles the earth at a distance of approximately 1000 miles and a speed in excess of 15,000 miles per hour serving as a reflector of radio signals from one point to another and distant point on the surface of the earth;

—the record-breaking flights of the X–15 research airplane;

—and finally, the spectacular recovery of the data capsule of the Discoverer XIII satellite.

All these are the results of a well planned and determined attack on this new field—an attack that promises very real and useful results for all mankind. Each of these satellites is destined to play an important part in broadening man's understanding of the cosmos in which he lives. While no one of them has been undertaken solely in an effort to achieve a "spectacular first" in the eyes of the world, each has resulted in just such a "spectacular first" in support of the desires of mankind for greater knowledge and understanding.

The United States leads the world in the activities in the space field that promise real benefits to mankind.

Reproduced from Public Papers of the Presidents of the United States: Dwight D. Eisenhower, 1960-1961. Washington, G.P.O., 1961. p. 643-644.

SPACE 25

Not so long ago space was prisfine. Even in the two decades following the orbiting of Sputnik, the two superpowers—the United States and the Soviet Union—were still the only truly significant actors there. And though they had previously launched some impressive unmanned satellites, their first astronauts were little more than tourists in space.

Even the magnificent moon landing was no more a precursor of human colonization of a new "continent" than was the first landfall by the Vikings in North America. And until recently most discoveries about the far universe were being made from earth-based telescopes.

But now, as we approach the twenty-fifth anniversary on October 1 of the day the U.S. National Aeronautics and Space Administration opened for business, much has changed.

A handful of satellites, several of them built or launched by European nations, are revolutionizing our understanding of the universe. In the United States private entrepreneurs have discovered space-for-profit, and businesses of all kinds are being formed to exploit the next 25 years of space activity. Around the globe developing nations are using communications satellites to catapult them into the twentieth century, while at the same time clamoring in international forums for a piece of the action in space. Suddenly laws governing the use of space are critically needed, but have yet to be written.

Even more important, the concept of space as a weaponless sanctuary—so reassuring to the world's citizenry during the first decades of man's journey into space—is threatened by the antisatellite weapons programs of the United States and the Soviet Union.

Symbolically and practically, now is a good time to assess where human beings are and where they are headed in space. With the help of expert authors and scores of space authorities, *Spectrum* examines in the following pages the profound changes that have taken place in man's use of space and considers their implications for the next quarter century. Join us as we voyage through "Space 25."

Ellis Rubinstein
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I. CROSSROADS IN SPACE

By all indications, the human race has reached a critical threshold in space. Man's first quarter century in space has been characterized by the establishment of unmanned probes and ephemeral manned outposts primarily by two pioneer nations, the United States and the Soviet Union. Now, many of the world's nations, private entrepreneurs, and the military establishments of the two superpowers are active in space. And in its silver anniversary year, the U.S. National Aeronautics and Space Administration is about to ask for a permanently manned space station. So mankind has reached a series of crossroads in space in many different arenas, and the paths chosen during these next several years will determine where we are when NASA turns 50 in the year 2008. Among the critical questions are these, broached in separate articles in this section:

- When is it advantageous to use man and when machine in space?
- What role should national military establishments play in space? Will antisatellite weapons, like those the Soviets have tested in the last decade and a far more sophisticated one test-launched from an F-15 jet by the United States last month, imperil world stability? Is it time for treaty talks?
- Will the internationalization of space—with more and more nations actively involved—bring those nations together in cooperative ventures and hence be a force for peace in the world? Or will it create another arena for national competition and associated frictions?
- Will commercial opportunities in space—now burgeoning in launching services, communications networking, earth-observation services, and proposed manufacturing in space—bring people together in fruitful enterprises that could raise living standards on Earth? Or will they be yet another source of international friction and further isolate the citizens of the poorest nations of the globe?

In this first section of *Spectrum*'s space issue, the editors and two expert authors examine each of these crossroads in turn—issues that blur in real life.

As an example, consider the complex debate now taking place at senior levels of the British government. As told to *Spectrum* by a government source, in 1985 the British hope to launch the first of three military communications satellites needed to enhance their current Skynet system. As important members in the European Space Agency (ESA), the British might be expected to select the ESA's French-built Ariane rocket as their launching vehicle. But some in the government prefer to use the U.S. Space Shuttle to launch the new satellites.

The critical issues in the debate have not been publicly identified by British authorities, but *Spectrum* has learned that with regard to national security, some officials feel more comfortable with the shuttle because of the experience the U.S. military and NASA have had with classified payloads. But this does not take politics into account. On one hand, the British worry about what they view as the present U.S. Administration's "troublesome" technology-transfer policies, fearing that these could hamper future cooperation. On the other, there are obvious personal and political affinities between Prime Minister Margaret Thatcher and her conservative government and President Ronald Reagan and his team.

Then there are economic concerns. Considering the British interest in the financial well-being of ESA, it might be in their long-term economic interest to launch with Ariane. However, the Ariane, though successful in its most recent bid to launch two satellites into orbit, lost two expensive payloads on a previous attempt.

This one case highlights many of the crucial issues being faced as man continues his adventure into space. Activity there is becoming increasingly complex, and the articles below attempt to elucidate what lies ahead.

HUMANIZATION: MAN OR MACHINE?

Since 1964, the National Aeronautics and Space Administration has advocated that the United States orbit a space station as the next logical step in the conquest of space. Now it appears likely that a Presidential task force—set up last April 11 under the chairmanship of National Security Advisor William Clark to study the idea—will this month recommend to President Ronald Reagan that the nation go ahead with the project, and a favorable response is expected.

Less certain, however, is whether the space station will actually be built in the 1980s. One problem is the multibillion-dollar cost of the project. In addition, the idea is vociferously opposed by many scientists who have been active in the unmanned space program and who have frequently criticized the manned projects in the past. However, it is supported by many in the aerospace industry and in Congress. The argument between the two groups represents yet another chapter in a debate that has surrounded the U.S. space program for two decades. The disputed question is: What are the proper roles of man and machine in space?

Arrayed in opposition to the space station are such leading figures in U.S. space research and in the exploitation of space as Louis Friedman, former director of advanced programs at the Jet Propulsion Laboratory and now executive director of the Planetary Society; Thomas Gold, an astrophysicist and former member of the Presidential Science Advisory Committee;

Eric J. Lerner Contributing Editor

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Harold Rosen, vice president of Hughes Aircraft and the chief designer of many communications satellites; Freeman Dyson, the physicist and space scientist; and James Van Allen, the discoverer of the Van Allen Radiation Belts.

While these men, though distinguished, are unlikely to have the political clout to kill the space station, their arguments will be used by space-station opponents in Congress and elsewhere. Now, as in the past, these men have contended that the focus on manned space flight, which has absorbed four fifths or more of NASA's expenditures [see illustration, p. 32], has unbalanced the space program, squeezing out unmanned missions with far greater scientific and utilitarian payoffs. They have argued that there are few tasks in space that humans can accomplish more effectively or cheaply than machines.

And some of them believe that the U.S. manned space program is shaped not by its own logic or development, but by such external factors as the economic requirements of the aerospace industry, NASA's own institutional drives, and the pushes and pulls of national prestige. The result, the critics argue, has been a haphazard series of expensive spectacles that have hampered rather than advanced the exploration and exploitation of space.

NASA's leaders and their supporters have in turn replied that, in the long run, human flexibility will more than compensate for the greater expense of sending men rather than machines into space. Far from starving unmanned exploration, manned-mission supporters say, the public and political support for space generated by the man-in-space approach has made possible the allocation of substantial sums toward space science in general. Supporters also contend that without the technology developed for manned space flight, the unmanned missions to the planets would have been impossible. They bridle at the characterization of Project Apollo and other manned space successes—which they consider immense technical accomplishments—as spectacles.

But even some of the harshest critics of today's manned space programs agree that eventually there should be a role for man in space. Also, no director of NASA has ever suggested that all resources be focused on manned space flight. Therefore the real dispute concerns what is to be the balance—for which tasks are men or machines better suited? And what are to be the criteria by which the funds available for space are to be allocated and the plans for space development drawn up?

Some of the key aspects of the controversy are largely economics-based: Are reusable manned vehicles cheaper than expendable unmanned ones? Are space tugs that can commute back and forth between low earth orbit and geosynchronous orbit practical and economical? Other equally important questions have no technical answers: Should scientific exploration, technological development, or national prestige be the highest priority of the space program? Is the maintenance of a U.S. manned presence in space itself a valid justification for space programs?

There have been three critical junctures in this ongoing debate. The first extended from the start of the U.S. space effort, in the wake of Sputnik, to the decision to go to the moon in 1961. The second, from 1968 to 1972, involved the post-Apollo direction of the space program and led to the decision to develop the space shuttle. The third is before us today: it requires laying out the course now that the shuttle is operational.

Four tasks seen for space station

In arguing for a manned space station as the next logical step, Robert Frietag, deputy director of the NASA Space Station Task Force, outlined four main tasks than can be accomplished. First, the station can be used as an orbiting laboratory to perform experiments in space—such as those that study space manufacturing processes, like electrophoresis. "Because of man's flexibility," Mr. Frietag said, "such experiments can be done far more effectively than by preprogrammed satellites or robots."

Thomas Paine, a former NASA director and the recently retired chairman of the Northrup Corp., points to the failure of the unmanned Viking craft to determine whether or not there is life on Mars as an example of a task that robots did not accomplish and that humans could have. Further, the space station can be used as a repair shop for damaged or partly obsolete satellites, Mr. Frietag said. Though the space shuttle is also intended to provide this function, repairs are limited to those that can be performed in the 7 to 10 days that the shuttle is in orbit. More complex repairs require bringing the satellite back to earth and putting it back up again. The space station, according to NASA, would enable a maintenance crew to perform repairs or to replace obsolete modules in a satellite—though the most thorough overhauls would still have to be done here.

"It's like the way the Army maintains its jeeps," explained Mr. Paine. "If you have to replace a spark plug, you do it right there in the field—that's the shuttle. If you need a tune-up, you bring it back to a field service garage—that's the space station. But if there's something major wrong, like the transmission, you have to send it back to the factory—that's returning to earth."

Satellites can also be resupplied from the shuttle or a space station, Mr. Paine added. The infrared astronomical satellite, for example, has less than a year's supply of liquid helium and can be refilled in space. In NASA's view, such repair operations will be cheaper than replacing communications and scientific satellites —especially tomorrow's much larger and more complex ones—even taking into account the added cost of maintaining the manned space station itself.

The third purpose of the space station, Mr. Frietag pointed out, is as a base for the launching of reusable space "tugboats" to take satellites from low earth orbit, where the station would be located, to geosynchronous orbit. This is viewed as cheaper than either direct launching of the satellites from the ground or launching with expendable upper stages from the shuttle.

Finally, the space station can be used as a staging area for the assembly and launching of large interplanetary probes, either manned or unmanned, the NASA official said. The payload would be carried aloft in sections by the space shuttle. Large earth-orbiting power stations, communications complexes, and earth-observation centers and other extended satellites could also be assembled in this way, NASA says, thus modifying the design of satellites and expanding their capabilities.

Differences over economic value

The core of the argument for the space station, including its first three uses, is essentially economic: the station–shuttle combination can more cheaply accomplish what is already being

done in space. But it is on these economic grounds that the space station's opponents attack it most sharply, as they formerly attacked the economic justification of the space shuttle itself.

"There's just not the slightest justification for the space station," said Thomas Gold, an astrophysicist at Cornell University in Ithaca, N.Y. "Since there is no long delay time in getting signals to and from earth orbit, you could have highly detailed operations carried out by remote control from earth."

Dr. Gold, a former member of the Presidential Science Advisory Committee, admitted that present remote-control technology may have to be improved to equal human capabilities fully for direct, hands-on manipulation, but he believes that such a development program would be far less costly than the $10 billion estimated for the space station. In addition, he believes that remote-controlled devices could be used for many other applications, such as underseas operations, mining, and so on. In space, combinations of programmed robots and remote manipulators—mimicking the actions of operators on earth—could, in Dr. Gold's view, not only perform experiments in space, but could also do the assembly tasks that NASA allocates to men, and do them more cheaply.

In rebuttal, Mr. Frietag said: "It just won't work. I don't believe you can build teleoperator robots or remote-control devices that can perform anywhere near as well as men—it can't be done." This, however is not a universally held opinion among present and former NASA officials. Many, including present NASA administrator James Beggs and former administrators such as Mr. Paine and Robert Frosch [see "Hybrids: the best of both worlds," p. 30], agree that NASA needs an expanded robotics program. But in varying degrees, each still argues that even with advanced teleoperators there is a need for men to be on the spot in space.

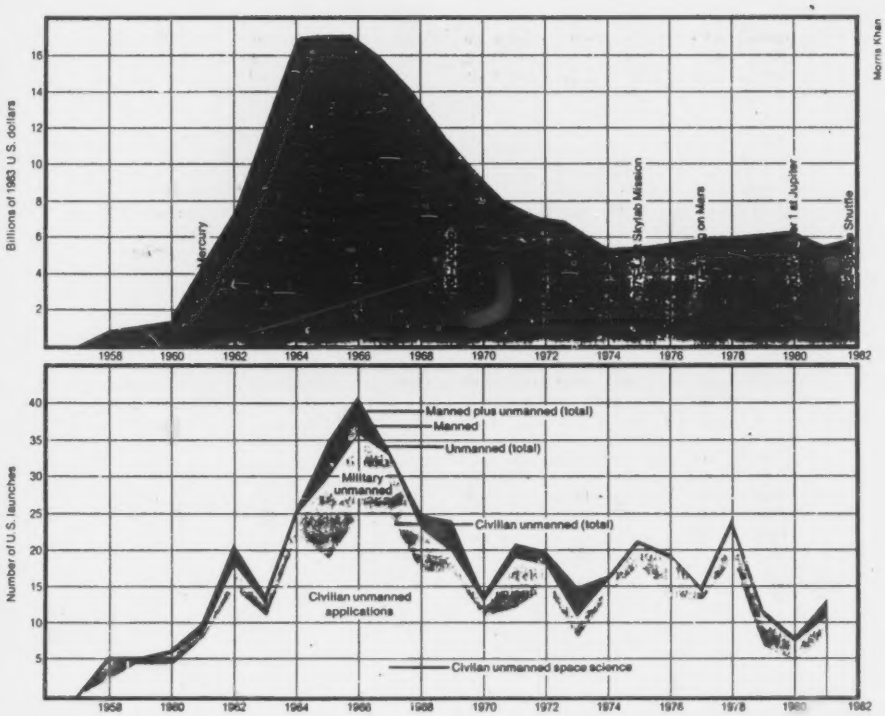
Basic NASA premises challenged

Perhaps even more fundamental is the question of whether many of the tasks assigned to the space station need to be performed at all. "It's incredible to even think about going to geosynchronous orbits, where the communications satellites are, to repair them," commented Dr. Rosen, the communications satellite designer at Hughes Aircraft who invented the Syncom satellite. "It takes far too much energy to get up there and down." Even for satellites in low earth orbit, "all you can do," said Dr. Rosen, "is minor repairs, like refueling their stabilizing rockets—and the shuttle can do that."

Mr. Paine replied that, though admittedly it will be too costly to get people into geosynchronous orbits to do repair work, future satellites in low earth orbit will be designed to be modified by people working in space. "Take the Space Telescope—it may be up there for 20 years or more," Mr. Paine said. "You might want to do an overhaul of the telescope without bringing it back to earth."

Nor would a manned space station be an appropriate place for space science, critics have pointed out. "A single, large platform is the last thing you want for space science," said Dr. Dyson, a physicist with the Institute for Advanced Studies in Princeton, N.J. "You need a large variety of orbits for scientific satellites, each tailored to a given objective. Besides, people get in the way of scientific experiments—they cause vibrations, for example."

This is one area where the space scientists have won a point. In its proposal for a space station [see also "The next 25: agenda for the U.S.," p. 91], NASA describes an entire space infrastructure composed of unmanned platforms—some for scientific experiments—in addition to the manned space base.



The massive rise in NASA spending during the early years of the Apollo program was followed by a fall to a much lower plateau (top graph). Both manned and unmanned space activity boomed while NASA's budget was high. But with the constricted budget of the 1970s and 1980s, during periods of intense manned activity (the moon flights, Skylab, and the space shuttle program) there have been fewer unmanned launches (bottom graph) for civilian applications and space science.

Another argument expressed by Dr. Dyson, is that even for manned exploration of the moon or Mars, a space station would not be useful. "You can see some value in men building a lunar base, for example, but you don't need a space station to do that —in a space station men are just sitting in a can."

NASA Administrator James Beggs disagreed. He told *Spectrum*, "We have been arguing the question of man's proper role literally from the beginning. There are papers around that go back to the Eisenhower years that discuss the question of manned activities versus automated unmanned activities in space, and there are arguments on both sides. We have not to date plumbed the depth of what man can accomplish in space.

"We have some experience from Skylab or Soyuz and of course from Apollo, Mercury, and Gemini that gives us some insights into what man can do. It's fair to say that Skylab, which was an enormously important step in NASA's exploration activities, was successful because the men deployed the solar sails and they put up the shade that was necessary in order to make it work. You might say, it didn't have to be designed for men, except that we did do a lot of precursor work in the Skylab that is just now reaching fruition. For example, the early experiments on electrophoresis in space were done by the men on Skylab, and I think that right now we see a tremendous potential for the experiments that are flying on the shuttle."

Critics of NASA's manned program even question what motivations, other than the avowed goals of the space program, are behind expensive projects like the space shuttle and space station. To Dr. Friedman and even station supporter John Logsdon, director of the Graduate Program in Science Technology and Public Policy at George Washington University in Washington, D.C. [see "NASA's dual challenge: serving yet striving," p. 86], NASA's own institutional existence is a major driving force. "NASA is not a science but a technology agency," Dr. Friedman said. "It is very heavily in favor of the development of capabilities and propulsion systems, not applications and exploration—they want continually to have that one, big project to engineer."

To Dr. Van Allen, a University of Iowa physics professor who is one of the pioneers of the space program, "the interests of the aerospace industry have always been a major factor." The big manned space programs require big, expensive rocket systems.

Willis H. Shapley, director of space and defense affairs in the Bureau of the Budget during the administrations of Presidents Kennedy and Johnson, said that when the decision was made to finance the space shuttle, "the Administration knew there was a big recession in California aerospace and the industry was lobbying very hard for the shuttle."

"It's often hard to know where the pushing from the industry leaves off and the pulling from NASA begins," according to Mr. Shapley, who also served in NASA as an associate deputy administrator for several years. Many officials, including four out of six NASA administrators, had close links with the aerospace industry either before or after their tenures, the argument goes.

But Dr. Logsdon derided such links between industry and NASA, asking: "Who do you want running NASA? Amateurs?" And Mr. Paine points to NASA's successes in communications and meterological satellites as well as its deep probes in space as proof that the space agency has always had a great concern for final goals, not just the technologies needed to achieve them.

Shortchanging of science feared

What concerns the critics of the manned space program is not merely that they consider the space station a waste of money, but that, given the overall constraints on NASA funding, they feel that the manned programs have squeezed out the far more scientifically rewarding unmanned space missions and will continue to do so. Dr. Van Allen, Dr. Gold, Dr. Dyson, and other space scientists believe that the vast majority of the benefits derived from the space program have come from unmanned, not manned, satellites and space probes.

They point to the changes in scientists' views of the solar system as examples. Mars, with its mysterious dry river beds, titanic volcanoes, and huge ice caps; Venus, with its sulphurous and baking surface; Jupiter, with its swirling storms that are larger than the earth; and Europa (one of Jupiter's satellites), possibly the only other body in the solar system possessing liquid water beneath shifting ice caps, have all been explored in the past 25 years by robot spacecraft. In the more utilitarian uses of space, worldwide communications have changed, weather forecasting has improved, and the exploitation of the earth's own natural resources has been enhanced by earth-orbiting satellites.

Manned mission proponents will respond that these very successes contradict those arguing that manned-mission budgetary allocations starve those for unmanned missions. Most of the solar-system missions just named were accomplished contemporaneously with the Apollo program, Mr. Paine pointed out. "They have the conviction," he said of the space scientists, "that the Office of Management and Budget, the White House, and congressional committees have a fixed amount to give NASA. So manned flight budgets come out of the planetary programs, according to them. This model is not realistic."

And yet it is undeniable that the U.S. unmanned space program has been severely cut back in the last decade. Though the overall NASA budget shrunk by two thirds in real dollars, allocations for the shuttle rose and space science and applications were almost squashed out of existence. Launches of civilian space vehicles, which had been running at over 20 per year in the mid-1960s, dropped to 12 to 15 per year in the 1970s and to 7 or 8 per year in the 1980s, when spending for the shuttle peaked.

Following the successful flights of the Viking spacecraft to Mars and the Voyager spacecrafts to Jupiter and Saturn, the solar-system exploration program was nearly eliminated. The U.S. portion of a mission over the poles of the sun, which was to have been performed jointly with the European Space Agency, was canceled (though, in the end, the United States will be contributing half the funds for the European portion of the mission). A Venus radar-imaging orbiter flight (recently resurrected) was originally stopped. And a Jet Propulsion Laboratory proposal for a Halley's Comet mission was rejected. Similarly many earth-orbiting astronomical satellites, such as the Advanced X-Ray Astronomy Facility, have been canceled or delayed, leaving the space telescope as the principal astronomical project of the coming decade.

Still, Thomas Paine is not convinced that the shuttle was the cause of these cutbacks. "Don't you give a major recession any credit?" he asked in an interview with *Spectrum*. "How about all other areas of university research where funding declined during the '70s? Was that due to the shuttle too?"

"There is no question that the space shuttle has delayed the development of space science," said Thomas Donahue, chairman of the National Academy of Science's Space Science Board and a professor of space science at the Carnegie Institution in Washington, D.C. "Once the decision was made at the start of the shuttle program not to go ahead with umanned research in parallel, and to phase out expendable-launch vehicles, the flight opportunities for science packages were reduced drastically."

Man or machine? A 25-year debate

The history of the U.S. space program has been marked by a running debate for 25 years over which goal should have priority—manned or unmanned exploration of space—and which criteria should be used to decide national prestige or space science.

The basic outline of the debate was already clear in the first months following the Soviet Union's October 1957 successful launching of Sputnik, the first man-made satellite. Before 1957 was over, General Bernard Schriever, then chief of the U.S. Air Force Ballistic Missile Division, had set up a committee under the chairmanship of Edward Teller, the nuclear physicist who recommended that the Air Force establish a vigorous space program, with the immediate goal of a manned landing on the moon.

The Air Force plan, dubbed Man in Space Soonest, or MISS, called modestly for a manned landing on the moon by 1965 at a cost of $1.5 billion (about 6 percent of the eventual cost of Project Apollo). Not to be outdone, the Army, with the help of its prized rocket designer, Wernher von Braun, developed its own plan—called Man Very High, later renamed Project Horizon—for getting to the moon by 1965. Though this plan had the more realistic price tag of $17 billion, it had as its far-fetched objective the establishment of a permanent 12-man moon base no later than 1966. The services both started studies aimed at justifying these goals in military terms—such as the use of a moon base to fire nuclear rockets at enemies on earth.

Eisenhower not impressed

President Dwight D. Eisenhower was not impressed by these arguments, and he was strongly supported in his view by his science advisor, James Killian, president of the Massachusetts Institute of Technology. Dr. Killian was skeptical of the military uses of space and urged a mainly scientific space program. Upon his recommendation and that of others, President Eisenhower established the National Aeronautics and Space Administration in April 1958 to oversee these scientific uses of space. However, under strong pressure from the Pentagon, the President did agree to a small initial manned effort, Project Mercury, whose aim was testing to see if man could survive in space.

Once organized, NASA put forward proposals remarkably similar to those of the armed services—not surprisingly, since many of the same men were involved in formulating both sets of ideas. In 1959, at the first meeting of NASA's Research Steering Committee on Manned Space Flight, NASA's Deputy Director George Low proposed a manned space flight that would culminate in a trip to the moon sometime after 1970. This plan was adopted by the committee.

President Eisenhower, still unenthusiastic (he would say later that "anyone proposing to spend $40 billion to get to the moon is nuts"), again turned to Dr. Killian for an assessment of whether the moon shot was scientifically justified. Dr. Killian had a report written by a committee of scientists under Donald Hornig.

The scientists' report concluded that "at the present time, man-in-space cannot be justified on purely scientific grounds." Dr. Killian himself added that "the really exciting discoveries in space can be realized better by instruments than by man." The President rejected NASA's ambitious moon plan, leaving the post-Mercury fate of manned space flight to his successor.

Three events radically changed this apparently dim prospect for manned flight. First, President John F. Kennedy replaced Keith Glennan, the first administrator of NASA, with James Webb. Dr. Glennan had acted as a middleman between those in NASA who were pushing for a manned program and the President who opposed it. And he had sympathy with some of the objections raised by the President's Scientific Advisory Board. Mr. Webb, a former director of McDonnell Aircraft Corp., was by contrast an enthusiastic proponent of the manned space program.

Then on April 12, 1961, the Soviet Union launched Yuri Gagarin into a single-orbit flight. He was the first man in space. President Kennedy was shocked into action. "Is there any place we can catch them?" Mr. Kennedy asked Mr. Webb. "What can we do? Can we go to the moon before them?" Three days later the Central Intelligence Agency's attempt to overthrow the Fidel Castro government in Cuba failed dismally at the Bay of Pigs.

A matter of national prestige

Suffering two blows to U.S. prestige in four days, the President sent a memo to Vice President Lyndon B. Johnson, then chairman of the Space Council, to see if there was any way the resources of the country could be mobilized to overtake the Russians in space "by a laboratory in space, by a trip to the moon, or by a rocket to land on the moon." The decision to send a man to the moon before the end of the decade was announced little more than a month later.

The basic justifications for the decision, in the eyes of those who made it, were summarized in a memorandum to President Kennedy from Mr. Webb and Secretary of Defense Robert McNamara. "It is man, not merely machines, in space that captures the imagination of the world," they wrote.

—*E.J.L.*

Even with opportunities for experimentation on the shuttle, life has become harder for space scientists, in Dr. Donahue's opinion. "Qualifying experiments for the space shuttle is a slow, painful, and costly project," he said, "because the science packages have to meet the rigid specifications of the manned program, which are much tighter than those of unmanned shots." Part of the problem is that astronauts must interact with the experiments, and this greatly complicates their design.

Dr. Dyson and other space scientists fear the problem will become worse if work starts on the space station. But, perhaps ironically, even as it appears that the Administration is about to throw its support behind the space station, so does it appear that the long space science drought may be over.

Might man and machine cohabit the heavens?

Even as the Administration of President Reagan edges closer to approving the space station, so too have the prospects of the unmanned program become considerably brighter, thanks to the efforts of the Solar System Exploration Committee (SSEC). Created by NASA to propose realistic unmanned missions for the next two decades, the SSEC heeded the advice of Presidential Science Advisor George A. Keyworth II, who said that in today's political and economic climate, billion-dollar missions would not be approved by the President. Rather, he challenged space scientists and engineers to propose lower-cost missions.

The SSEC, primarily under the leadership of Noel Hinners, now head of NASA's Goddard Space Flight Center in Greenville, Md., has proposed a minimum budget for the next decade: the spending of $300 million a year for pared-down probes of the planets. The committee's highest-priority projects are a Venus radar mapper (a smaller version of the canceled Venus orbiting imaging radar), a Mars geoscience and climatology orbiter, a probe to Saturn's giant satellite Titan and a rendezvous with a comet and asteroid sometime after the Halley's Comet visitation. As described by Theodore Simpson [see "Solar-system sorties: ending the hiatus," p. 84], the committee hopes to reduce expenses by designing a basic spacecraft, the Mariner Mark II, which could be slightly modified for several of the missions, each

of which would cost no more than $200 million. As Dr. Simpson reported, response to date from the Administration and Congress to the SSEC proposal has been favorable, and the Venus radar mapper is included in NASA's current budget proposal.

Further, in 1984, the SSEC will issue a second part of its report, which will propose a set of more expensive, extremely ambitious programs for unmanned space science. Thus, should there be a sustained recovery of the U.S. economy, which might encourage the current Administration to loosen NASA's purse strings, or should the 1984 Presidential election result in a new administration favoring increased space spending, NASA will be ready.

But whether it will be ready to increase substantially what former Administrator Frosch conceives of as the hybridization of space, by upgrading its programs in the use of automation, is far from clear. Nor is the old debate about how best to use man and machine in space likely to disappear in the foreseeable future. ◆

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MILITARIZATION: PEACE OR WAR?

While the news media were pinning the label "Star Wars" on President Ronald Reagan's proposal last March 23 to step up research on ballistic-missile defense, the United States military was slipping quietly into a new era in space. The turning point was a largely unheralded change that had occurred six months earlier beneath Cheyenne Mountain in Colorado.

The granite mountain's hollowed interior has long housed the North American Aerospace Defense Command (Norad); it is here that an enemy missile attack would first be confirmed and an alert sent to the President of the United States and the Prime Minister of Canada. But on Sept. 1, 1982, a second tenant moved into the mountain: a new Air Force organization called Space Command. Its purpose is to consolidate the Air Force's diverse satellites and space programs under a four-star general, James V. Hartinger.

Space Command is the first high-level organization in the military created solely to operate systems in space, inspiring comparisons with the inauspicious beginning of the Air Force as a unit of the Army's Signal Corps. In fact, the Air Force is pressing to make it a unified command, serving as an umbella organization to operate the military space systems of all four services.

A shift in policy under way

This institutional change is occurring on the threshold of a fundamental shift in the military presence in space. Ever since Sputnik I, the first artificial satellite, launched by the Soviet Union in 1957, the major military establishments have used satellites for communications, intelligence, and other military support functions. But for many years, no military organization of any nation deployed orbiting weapons.

The Outer Space Treaty of 1967 forbids placing "weapons of mass destruction" into earth orbit, which includes some early antisatellite weapons that used nuclear explosives. Furthermore, the Antiballistic Missile Treaty of 1972 explicitly forbids tampering with the "national technical means of verification" of the treaty, including intelligence satellites, which are widely recognized as promoting stability. In fact space was long considered a sanctuary until both superpowers developed nonnuclear antisatellite weapons, like the Soviet Union's hunter-killer satellite, which creeps up on other satellites and destroys them by spewing shrapnel. In response to the Soviet weapon, the U.S. Air Force seeks to deploy its own antisatellite weapon, and the Space Command would operate it. In addition, the Department of Defense is planning to spend $243 million next year on research into laser and particle-beam technology for antisatellite and other weapons in space. Last year, for the first time since 1960, the DOD spent more money on space than NASA did. The Soviet Union, according to the U.S. Defense Department, is already spending three to five times more than the United States on developing such weapons.

These events have provoked fears of an arms race in space. Some experts say that the world is at a turning point; unless agreements are made soon to stem the development of space weapons, a Pandora's box will be opened. Experts disagree, however, as to whether a ban on space weapons is even feasible.

The DOD has been criticized also for considering weapons systems that some scientists believe are unworkable—space-based lasers, for example, might entail insurmountable engineering problems of weight, power, beam aiming, and others. Some military specialists say that weapons in space are not valid militarily—in other words, since wars are fought to gain an advantage on the ground, it makes little sense to build elaborate weapons in space.

What impact will the creation of the Space Command have on the introduction of weapons in space?

Before the birth of the Space Command, space technology was largely the province of engineers, not combat commanders. At research and development facilities like the Air Force Space Division, engineers built and launched satellites with little guidance from high-level commanders in other divisions of the Air Force, where the systems often were used. In fact, in the early days of space, recalled John Logsdon, chairman of the Department of Space History of the National Air and Space Museum, very few generals supported extensive use of space technology. "Leaders of the career military tend to be skeptical about changing the way they do business," Dr. Logsdon said. Space enthusiasts could be found in the military, he noted, "but with very few exceptions they were colonels or in the lower ranks—the so-called space cadets."

Recent years, however, have been marked by a growing appreciation by the Air Force leadership of the military importance of space—and a growing dependence on its satellites for communications, intelligence, and the like. By Fiscal 1983, the U.S. military and intelligence space budget had quadrupled in less than a decade to $8.4 billion, and the Air Force decided it was time to place its space programs under an "operational command." The Space Command will identify where space systems are needed and define their specifications. The Space Division, set up years ago, will develop and build the systems, as it has in the past. After the systems are ready for use, the Space Command will control them in peacetime and devise strategies for their use in war. The command will also enter its space systems into interservice military exercises to decide what new capabilities they need.

The Space Command is based on the Air Force's recognition that space is no longer an R&D laboratory but an arena for military operations. The command has geared up quickly for its new responsibilities. Last May it began ground breaking on a $1 billion Consolidated Space Operations Center near Colorado

Fred Guterl Associate Editor
Carol Truxal Contributing Editor

Springs, Colo., which it says will become "the centerpiece for all military operations in space." The center will be equipped to control half of all military satellites, and by the end of the decade it will control DOD flights of the U.S. Space Shuttle, now controlled from NASA's Johnson Space Center in Houston.

Information on the whereabouts of shuttles and satellites will be fed to the center from inside Cheyenne Mountain. Linked to a worldwide network of radar, telescopes, and deep-space cameras around the world [see Fig.], computers now keep track of almost everything in orbit—some 4900 objects, including both useful satellites and chunks of debris—as long as it is larger than a basketball and within 23,000 miles of the earth. This space surveillance network is now operated by Norad. In operation since the early 1960s, it keeps a particular eye on Soviet satellites, on objects falling from orbit (like the U.S. Skylab and the nuclear-powered Soviet Cosmos 954), and on any object that looks like an approaching missile.

But the strength of the military's new commitment to space is measured best not by its awesome facilities, but by the stature of the man who runs them all, General Hartinger. For the last three and a half years, he has been commander in chief of Norad—the man who makes the ultimate decision about whether a heat flash and radar blip picked up by early-warning sensors is indeed a Soviet nuclear attack. Last fall, when Gen. Hartinger became commander of the Space Command, the military space program for the first time was placed under the guardianship of a four-star Air Force general.

"You can't do anything in the military unless you've got a four-star general advocating it," said Hans Mark, deputy administrator of NASA and former secretary of the Air Force. "The real reason for Space Command is to have a four-star general out there with SPACE written across his chest."

Gen. Hartinger calls himself "the honest broker for space in the operational world." He will be advocating, among other things, that space systems be better equipped to survive conflict. The general sees the Soviet space threat as real and as a strong reason for forming the Space Command.

Soviet buildup emphasized

The U.S. Defense Department's booklet, *Soviet Military Power: 1983*, says that in the past 10 years the Soviets have been launching four to five times as many spacecraft each year as the United States. The Soviet Union is also developing a heavy-lift launcher, the booklet notes, "that will be able to place payloads at least six to seven times the weight of those of the U.S. Space Shuttle into orbit."

The launching vehicle will help the Russians develop "a large manned space station by about 1990 to maintain a military presence in space," the booklet continues. The strength of the Soviet manned program is emphasized: it has placed seven space stations in orbit since 1971, enabling cosmonauts to amass "twice as many man-hours in space as U.S. astronauts" have amassed.

Such statistics must be viewed with caution. "There is a real war of rhetoric going on nowadays between the U.S. and USSR about whose space program is more military," said Marcia Smith, a Library of Congress space specialist. In truth, since the Soviet Union does not split its military and civilian space programs into separate organizations, as the United States does with the DOD and NASA, it is hard to determine how much of the Soviet space program is military. U.S. observers can guess whether a Soviet space station is doing at least some military work by whether its cosmonauts are from the military and by the encryption of its telemetry. But the bottom line, added Ms. Smith, is that "it's very difficult to figure out exactly what they are doing up there."

The fact that the Soviet Union launches more satellites than the United States is also misleading. U.S. satellites often are more advanced and stay in orbit longer.

Still, the sheer number of Soviet launchings worries some U.S. generals. "It shows they have a massive infrastructure to mass-produce satellites and boosters," said Major General John H. Storrie, the Air Force's director of space plans and operations in the Pentagon.

The Soviet Union, he fears, may challenge U.S. technological brain with sheer brawn. The Soviet antisatellite weapon is a case in point. Though hardly sophisticated, it works, and it has been tested in space for more than a decade.

The DOD booklet calls the deployment of the Soviet antisatellite weapon a clear sign that the USSR recognizes space as an "arena in which to conduct war." This implies to some U.S. generals that the nation can no longer afford to view space as a sanctuary, a refuge for nonaggressive reconnaissance and communications satellites. The United States needs its own antisatellite weapon, said Gen. Hartinger, "to protect its interests in space."

Gen. Storrie explained, "We feel we are in space right now where we were with airplanes back in World War I. Airplanes were first used for reconnaissance. The German aviators and the French and English aviators would pass each other on their way to the other side's trenches to do their reconnaissance. Then they found out that the commanders who had the best reconnaissance were winning the battles. So one day someone took a .45, and as he passed the other side's plane, took a shot at it. The next day the other plane had a machine gun mounted on its back. And so on, until they were all involved in air battles."

Gen. Hartinger insists that "we are not militarizing space." Yet the Air Force is clearly grappling with a new perception about the role of space in military operations and, with the better space technology and resources now at its command, it is creating the infrastructure needed to translate that perception into reality.

The technology for placing weapons in space already exists. "Everyone says, 'You don't have to worry about lasers and particle beams—they're 20 years away,'" noted Ms. Smith. "The point is you don't need lasers and particle beams to fight a war in space. You can do it with conventional technology. They have it, and we're developing it."

Early uses of space

In 1958 the U.S. Navy began developing its first navigation satellite, Transit 1A. In 1960, three months after the Soviet Union put an end to U.S. spy planes flying over its country by shooting down a U-2, the United States launched its first photographic reconnaissance satellite, Discoverer 13. Two years later the first military weather satellite flew. By the late 1960s, the DOD, bor-

rowing an idea and much technology from NASA, put a military communications satellite into geosynchronous orbit.

These early satellites were so-called support systems; they did not fight battles, but provided crucial services to troops and fleets that did the fighting.

"One must distinguish between the militarization of space and the weaponization of space," said David Williamson, who worked as assistant to the administrator of NASA from 1959 to 1982. "The militarization of space began 25 years ago—that is, the use of space for military functions. They don't have to be aggressive or explosive to be military."

Support satellites continue to be the heart of the military's involvement in space, and hundreds of millions of dollars are spent each year on upgrading these satellites. The next generation of navigation satellites, the Global Positioning System, will enable planes, troops, and ships around the world to pinpoint their positions to within 50 feet by time-ranging radio signals from a constellation of satellites equipped with atomic clocks. The latest communications satellites offer jam-resistant, superhigh-frequency transmissions. The intelligence satellite KH-11, used by the U.S. Central Intelligence Agency, has multispectral scanners with resolution that is "20 to 30 times better than Landsat," speculated Thomas Karas, author of *The New High Ground: Strategies and Weapons of Space-Age War* (New York: Simon & Schuster, 1983).

As the capabilities of such satellites have improved, the U.S. military has grown more dependent on them. For instance, more than two thirds of U.S. long-distance military communications are now carried by satellite. But despite dependence, the military has until recently emphasized the capabilities of fragile devices rather than their capability to survive in war. For years, space was viewed in the United States as a sanctuary and not a potential battle zone. This view was based in part on technological optimism—the feeling that no one could possibly reach U.S. satellites—and in part on the fruits of diplomacy.

For one thing, a series of international treaties signed in the 1960s and early 1970s limited military uses of space. The 1963 Limited Test Ban Treaty outlawed nuclear explosions in space. The 1967 Outer Space Treaty banned the orbiting of "weapons of mass destruction"—taken to mean nuclear bombs and biological, radiological, and chemical weapons. In 1972 the United States and the Soviet Union signed SALT I agreements barring both superpowers from placing antiballistic missile defenses in space and strictly limiting the number of defenses that could be placed on the ground.

The overall effect of such treaties was to create a feeling, as Dr. Logsdon put it, "that you could get away with deploying military systems in space without worrying about protecting them. There was a hope that space would be a sort of military sanctuary."

The race for antisatellite weapons

Ironically, however, by the mid-1960s both superpowers were working on weapons that could undermine that sanctuary—antisatellite (ASAT) weapons.

In 1964, the U.S. Army began tests to see if its Nike Zeus antimissile system could hit satellites, and the Air Force began testing its Thor ballistic missile as an antisatellite weapon. Both weapons, it turned out, had limitations: they could only hit targets that happened to fly overhead, and because the missiles had nuclear warheads, they would release electromagnetic pulses that were likely to disable electrical systems on the ground.

In 1968, the Soviet Union ran the first operational test of its ASAT explosive mine, tucked aboard a small satellite and launched by a modified SS-9 ICBM. It could destroy a satellite by entering an orbit approximating that of the target, slowly creeping up on it, and then exploding, battering the target with shrapnel.

As the USSR continued to test the weapon in the 1970s, the concern it aroused was, to some military observers, out of proportion to the threat, because most U.S. satellites—the communications and navigation satellites and many intelligence satellites—were in orbit higher than the Soviet ASAT could reach. The only nonclassified satellites that are vulnerable are low-flying weather and reconnaissance satellites.

In 1978 President Jimmy Carter started negotiations with the Soviet Union to try to talk it out of developing its ASAT. The talks were unsuccessful. "The Soviets said, 'What about the shuttle? It's a bomb can,'" Mr. Williamson recalled. The talks were suspended, and after the Soviet Union invaded Afghanistan in 1979, they were never resumed.

The Pentagon, however, responded to the Soviet ASAT threat in two ways. First, it placed more emphasis on ensuring that satellites could survive conflicts; it has given many of its satellites at least a modest ability to maneuver out of a weapon's way—a fairly easy defense against the sluggish Soviet ASAT—and it has started to use satellites redundantly. Second, it began developing an ASAT of its own.

The U.S. Air Force plans to test its first ASAT at Edwards Air

Force Base in California. Unlike its simpler Soviet counterpart, the weapon is not launched from the ground but from the air. A two-stage rocket is strapped to the belly of a modified F-15 plane. After the plane takes off, the rocket sends a miniature homing vehicle hurtling toward the target satellite at 8.5 miles per second—15 times faster than a bullet leaves the muzzle of an M-16 rifle, said Dr. Karas. Guided by a long-wave infrared sensor, the homing vehicle maneuvers toward a target by firing tiny rockets on its sides. The changing position of each rocket on the spinning vehicle is monitored by a laser gyroscope. Because the vehicle heads directly for its target, rather than co-orbiting like the Soviet ASAT, it completes its job more quickly—in a matter of minutes after the F-15 launches the rocket.

The Defense Department hopes to have 30 of these weapons by 1987. The United States needs an ASAT, Gen. Hartinger said, since the Soviets appear to be working on a booster that by the end of the decade could threaten even U.S. geosynchronous satellites.

Some critics of the U.S. ASAT argue that such weapons could lead to innocent satellite malfunctions being construed as enemy attacks. This, they say, could lead to an exchange of retaliatory strikes, jeopardizing valuable surveillance and communications satellites and creating an unstable political climate. Some critics argue that a war could be started this way.

Resolutions have been introduced in the U.S. House of Representatives and Senate urging the President to try to negotiate a ban on ASATs with the USSR before the U.S. weapon becomes operational. Some officials say, however, that the Soviets are unlikely to negotiate away a capability that they have and the United States does not yet have.

Are laser weapons next in space?

Daniel Deudney, senior researcher at the Worldwatch Institute, Washington, D.C., believes that if the U.S. ASAT becomes operational the Soviets may counter with an even more capable model, perhaps a laser ASAT orbiting in space. And although an initial Soviet laser weapon would have "negligible capabilities, the psychological impact, as with Sputnik, will probably be traumatic, leading the United States to embark upon an ambitious crash program to put battle stations into orbit. The result will be a full-scale arms race in space," Mr. Deudney said.

The Soviet Union already has a large directed-energy research program, including laser-weapons studies, which the DOD estimates to be from three to five times bigger than its own efforts. Rumors that the Soviet Union is on the verge of deploying a laser weapon have circulated for most of two decades; lately they have been increasingly supported by DOD reports. Robert Cooper, director of Darpa, said during recent testimony before a House panel, "The Soviets could launch the first prototype of a space-based laser antisatellite weapon in the late 1980s or early 1990s."

The appeal of laser beams as weapons is that they have no mass—thus no propellant is required to hit a moving target. Satellites are relatively easy targets for laser weapons, since their fragile electronics can be upset by modest amounts of power. A harder task would be using lasers to destroy incoming ballistic missiles—particularly in the comprehensive "defense of homeland" scenario suggested by President Reagan in his March 23 address.

The President never specified what technology he thought might be used to defend the U.S. public in an all-out missile attack. Some military experts call for three lines of defense: a set of satellites bearing conventional weapons orbiting over the Soviet Union to knock out missiles during their boost phase; another set of satellites with laser weapons to fire at warheards that sneak past the first defense; and ground-based U.S. rockets to mop up any remaining warheads.

The laser portion of such a defense theoretically could be any of a number of devices now under study. Chemical lasers, pumped by the combustion of hydrogen and fluorine, have received the most attention. The DOD and the U.S. Department of Energy are exploring other options for directed-energy weapons, including free-electron lasers and particle beams. Particle-beam weapons for space have been under study at the Los Alamos (N.M.) National Laboratory since 1974. Another possibility is the nuclear-bomb-pumped X-ray laser espoused by Edward Teller; it is reportedly undergoing successful testing at the Lawrence Livermore Laboratory in California.

General Richard Henry, recently retired commander of the Air Force Space Division, Los Angeles, Calif., said "A laser that is capable of destroying a ballistic missile warhead would require a spacecraft weighing several tons at low altitude and a command and control system that would boggle the imagination. In theory it could be done, but we would need a breakthrough."

Breakthroughs can happen, noted Gen. Henry, recalling a similar situation in 1953, when the United States was trying to build an intercontinental ballistic missile. "We knew in theory we could do it, but we didn't know how," he said, "because in those days our bombs weighed 10 000 pounds." The breakthrough was inventing a nuclear weapon "that weighed an order of magnitude less." President Reagan's initiative to begin research on antiballistic missile systems, Gen. Henry said, makes sense as a precursor to a similar breakthrough in laser or beam weapons.

Beam weapons viewed as vulnerable

Critics of space laser and beam weapons point out, however, that even if a device could be built, it would be as vulnerable to attack as any satellite. And, they say, the weapon might easily be tricked and its power exhausted if an enemy launched fake missiles first or if the missiles were protected with heat shields. Such strategies would cost far less than beam weapons.

Mr. Williamson, the former assistant to the administrator of NASA, called a missile-defense strategy unrealistic. Even if a U.S. antimissile system turned out to be 95-percent effective, he said, 9 megatons of Soviet nuclear explosives could still leak through. A 13-kiloton weapon, he noted, left 105 000 people dead at Hiroshima and Nagasaki.

President Reagan did not say the United States should definitely build a missile defense, but he hopes that someday the U.S. technological genius may find an alternative to the policy of mutual assured destruction. "Wouldn't it be better," he asked, "to save lives rather than avenge them?"

Gen. Hartinger argued, "Since World War II we've had only offense, no defense. I think to develop a defense against ballistic missiles has to promote stability and balance in the world."

Dr. Logsdon does not agree: "I think it would be the most destabilizing thing you could think of. If you were someone who felt threatened by your opponent and you saw him building walls around himself, you'd make sure that if you were ever going to attack, you'd do it before the walls were complete."

Given the growing accuracy and megatonnage of each superpower's ICBMs—for example, Cheyenne Mountain could no longer survive a direct Soviet nuclear hit—both nations may be moving toward a "first strike" posture, some weapons critics say. According to this scenario, if a superpower launched the first strike, it would suffer far fewer losses than its opponent, which might not be able to retaliate with full force.

"This creates an unstable situation, for it creates an incredible

incentive to go first," said John Pike, staff assistant for space policy at the Federation of American Scientists, Washington, D.C. He believes the incentive would only increase if the superpowers had laser missile defenses. "My impression," he explained, "is that a laser would not be effective against a well-coordinated first strike but might be a highly effective defense against a poorly coordinated retaliation."

World stability can only be promoted, said Gen. Hartinger, "if we reduce both nuclear arsenals to an equitable, verifiable, more rational level, and then bring defense into the game."

The United States will be forced in the next five years to make some key policy decisions about the future of its military involvement in space. Congress will vote on whether to procure the new antisatellite device, a major step in commitment to the weapon. The Pentagon will decide whether to go ahead with the demonstration of a space laser. Congress will vote on four resolutions supporting the banning of weapons from space, and the President will decide whether to seek negotiations with the Soviet Union over space weapons. ◆

INTERNATIONALIZATION: HARMONY OR TENSION?

When President John F. Kennedy decided in 1961 to put the United States ahead of the Soviet Union in space technology by sending men to the moon, telephones were virtually nonexistent in Indonesia. But now the situation for both Indonesia and the United States has changed.

Last June the U.S. Space Shuttle released from its cargo bay the third Indonesian telecommunications satellite, Palapa-B [Fig. 1]. Far from having no telephones, Indonesia, a 3000-mile string of islands along the equator in the Indian Ocean, plans to lease circuits on the satellites to neighboring countries for regional telephone service and television broadcasting, in addition to using the satellite for its domestic needs. And far from exploiting space solely for scientific reasons, the U.S. National Aeronautics and Space Administration launched Palapa-B for a fee, and it had to bid for the launch contract against the European Space Agency (ESA).

Space programs are no longer solely a flexing of technological muscle by the United States and the Soviet Union. Today satellites and other space developments are important economically and militarily for many nations, and this dependence has fostered both greater cooperation and competition between nations than existed in the pioneer years in space.

NASA ended the Apollo moon program a decade ago and is gearing for competition from other countries that have developed the capability to launch satellites. Intelsat, the internationally owned corporation that manages a world telecommunications network, has over 100 participating countries, but its dominance began to erode when NASA launched Palapa-B and the ESA launched the European regional communications satellite last June on its Ariane booster. In addition, several regional and domestic satellite communications systems are being planned for the next five years by India, Australia, and Arab and Latin American countries.

For some developed countries, space technology has become an often crucial aspect of military activity and an expanding industry. For developing countries, satellite communication is a way to leapfrog the costly, slow development of telephone lines and microwave transmission stations. Remote-sensing satellites provide information about countrysides that no other affordable method can give, and direct-broadcast satellites can open the way for inexpensive television reception in remote regions.

The importance of space technology to the well-being of nations has made it the subject of debate at the United Nations. Those debates often concern the fears of the developing world of exploitation by the industrial powers, upon whom they depend for the technology. They want treaties that guarantee them the right to control both what is broadcast into their countries and the dissemination of information gathered about their lands by remote-sensing satellites. They argue that the geosynchronous location of communications satellites is a precious resource that should be divided equitably between all countries, regardless of ability to use it. Several equatorial countries even claim sovereignty over the geosynchronous arc above their lands.

Fred Guterl Associate Editor

Space progress as a symbol

In the early 1960s, space technology was important primarily to the United States and the Soviet Union, the two industrial and military superpowers caught up in the cold war, where success was measured in terms of international prestige and stockpiles of missiles able to launch nuclear warheads. Since other countries also recognized the potential of using space, the two superpowers vied for world leadership. The United States poured billions of dollars into the booster and satellite technologies, among others. The manned space program captured public imagination and created an aura of U.S. technological supremacy.

As the politics of the cold war warmed during the detente of

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the 1970s, space technology again provided the symbols. In 1975 a U.S. Apollo spacecraft and a USSR Soyuz spacecraft docked in space. Television cameras transmitted to the earth images of U.S. astronauts and Soviet cosmonauts shaking hands in space.

But the reluctance of both the Soviet Union and the United States to reveal technological information during the Apollo–Soyuz project underscored the limitations of cooperation in space. Both countries designed the mission to require little exchange of technology. Only the interface between the two spacecraft required an exchange of blueprints: the Soviet design was used.

The Apollo–Soyuz project somewhat improved cooperation between the two superpowers, although not as much as NASA had hoped, said Marcia Smith, a specialist in space and telecommunications at the Library of Congress in Washington, D.C.

Europe begins to compete

The countries now in the European Space Agency began negotiations in 1961 for a cooperative European effort to develop a rocket-launching capability and a space science program. The ESA effort has produced the Ariane booster and also the Spacelab, which is to be launched next month in NASA's space shuttle [see "Spacelab: The biggest joint ESA–NASA effort"].

The European effort illustrates how several nations, often with conflicting priorities in space, can work out compromises and pool their resources. The French, for example, were adamant about developing booster technology, while the West Germans and the British wanted to stress payload systems and manned space activities. Both goals eventually were met in the largely French-backed Ariane booster and the largely German-backed Spacelab. Officials of France's space program persuaded their European counterparts to contribute to the Ariane by arguing that the United States would otherwise continue to control Europe's access to space. The German initiative to develop a manned program led to involvement in the Spacelab, which entailed cooperating with NASA on the space shuttle program.

In the beginning of European involvement in space, French space officials stressed the value of space technology to national industrial health. The French policy under President Charles de Gaulle was to be staunchly independent, and that included the independence of the French space program from NASA. Independence meant the capability to launch satellites: as long as NASA had a monopoly on booster technology, the French feared the possibility of NASA vetoing a French mission.

The European Launcher Development Organization (ELDO) was formed in 1964, mainly through French and British efforts. It had the backing of military leaders who believed that booster technology was essential to an independent European military force. It also had the support of European aerospace companies and defense contractors, who had much to gain from expensive contracts.

That same year, the European Space Research Organization (ESRO) was formed, by contrast, mainly to unify in Europe what had been fragmented cooperative efforts with NASA in space science, and also to allow nations without space programs to participate. It had the backing of scientists who felt that Europe did not have the resources to compete with NASA in booster technology and that money would be better spent developing scientific experiments. They also felt that Europe had no reason to fear a NASA veto of launches for scientific projects, since the U.S. space agency had always been cooperative in launching European experiments.

A dispute over the launching of an applications payload acted as a catalyst in the formation of the ESA and the decisions to develop the Ariane booster and Spacelab. Officials of the French space program asked NASA to launch the Franco–German Symphonie satellite, which they said would be used for domestic telecommunications. But then some French officials made statements indicating that the satellite was to be for commercial international communications. At the time, however, the Intelsat agreements, to which France was a party, referred to Intelsat as the single global communications system. The U.S. State Department interpreted the wording to mean that no member nation could deploy a commercial international satellite system.

On learning of the French official's statements, the U.S. State Department asked the French government to sign a pledge that its satellites would not be used for commercial international com-

Spacelab: the biggest joint ESA–NASA effort

The Spacelab mission scheduled for launching Oct. 28 in the U.S. Space Shuttle is the fruit of the most extensive cooperative effort between the European Space Agency and the U.S. National Aeronautics and Space Administration. The billion-dollar program has weathered some difficulties due to delays in development and to an early misconception that flights would be more frequent than they are now being planned. Nevertheless, it will soon give scientists new information on the earth's atmosphere, materials processing, astronomy, and medicine, to name just a few areas.

The project began in 1973 when NASA and the European Scientific Research Organization, a forerunner of the ESA, agreed that the European organization would be responsible for designing and building the Spacelab, and that NASA would provide the shuttle to launch it. The orbiting laboratory, designed to fit inside the shuttle's cargo bay, can be configured for manned or unmanned operation, as well as for holding instruments of widely varying sizes and requirements. (Although the Spacelab project is moving ahead successfully, officials of the French space program said Spacelab might not have been the best choice the ESA could have made in the early 1970s, when NASA offered the agency a choice between the Spacelab and a space tug. As envisioned, the tug would have ridden in the shuttle's cargo bay and then flown from the shuttle's low orbit to a geostationary orbit 22 000 miles high to service satellites.)

On its first mission, Spacelab will carry two payload specialists—one from Europe and the other from the United States—and 37 experiments, mostly European. Afterward, NASA will become the owner of Spacelab, and the ESA will have achieved its first successful manned space flight.

The frequency of Spacelab launchings in general has given rise to the dissatisfaction of French space officials. Ten years ago, it was hoped that Spacelab launches would occur more often than is now anticipated. Hubert Curien, president of the Centre National d'Etudes Spatiales, the French space agency, said: "People didn't realize it would be very difficult to get a ticket to fly in Spacelab—it will be the same for a U.S. citizen and a European."

The high cost of Spacelab launches has been a surprise to NASA and ESA officials alike. Mr. Curien's assessment of the problems of access to Spacelab is fair, according to Arnold Frutkin, formerly head of international affairs for NASA, but they are not unique to Spacelab. For other programs, including the U.S. Space Shuttle and ESA's Ariane, schedules and cost estimates have deviated from plans, thus delaying access, he said.

—*F.G.*

This October, the European Spacelab will ride in the U.S. Space Shuttle's cargo bay, configured with a long pressurized cabin where two scientists will work (top right). In other missions, Spacelab can be configured with a smaller cabin and instruments for earth observation (right), or completely unmanned with instruments for solar physics (far right).

munications. A debate ensued. Officials of the French space program contended that NASA was refusing to launch the satellite, which aroused feelings in Europe that space programs would be subject to NASA's whims unless European booster technology became a high priority.

Arnold Frutkin, who at the time was the head of international affairs for NASA, said the space agency did not refuse to launch the satellite, but rather set the condition that the satellite could not be used for commercial international communications. In fact, he said he felt it was excessive for the State Department to demand that the French sign a pledge. Moreover, "we really controlled the situation," he noted. "If the French had gone ahead and violated the Intelsat agreement, then we could have refused to launch another French satellite, and they couldn't have kept the system going with only one."

Two Symphonie satellites eventually were launched by NASA, but only after the nations belonging to ESRO and ELDO agreed in 1973 on a plan to combine the two organizations into the European Space Agency and to begin development on the Ariane booster, the Spacelab, and a maritime communications satellite.

Europe also created a single voice for articulating its objectives in space. By the early 1970s the rigid guidelines for participation in ESRO and ELDO had begun to seem obsolete. Under these rules, whenever either organization undertook a project, participation by all member nations was mandatory. The money each country contributed to the organizations was based on the size of its gross national product. As space technology became increasingly important to each country, the ESRO convention was extended to include applications projects in addition to the scientific projects, and some members began to consider producing and using their own satellites as an important element in their future industry.

I. European cooperation: who gives what (percent)

Country	To ESA (in 1983)	To Ariane (since 1973)	To Spacelab (since 1973)
France	28	64	10
West Germany	22	20	56
Great Britain	18	3	7
Italy	14	2	18
Others*	20	11	12

*Includes the Netherlands, Belgium, Spain, Switzerland, Sweden, Denmark, and Ireland and the non-ESA members Canada, Austria, and Norway, which each contribute 5 percent or less.

The ESA convention drafted in 1975 infused flexibility into joint ventures. It stated that involvement in applications programs is optional, although all members still must contribute equally to scientific efforts. Under its terms, each participating country can also choose how much money it wants to contribute to each program [see Table I]. Currently, France contributes slightly over 60 percent of the funds to develop Ariane, for which about $650 million has been spent since the project's inception. West Germany, in line with its emphasis on payload programs, contributes over 50 percent of the Spacelab budget, which totals about $900 million since the beginning of the project.

Developing countries seek access to space

Meanwhile the developing countries are calling on the developed countries to provide better access to sophisticated space technology. And the technology has become inexpensive enough to encourage many countries to buy their own satellites or form satellite consortia with neighboring countries for regional communications. Owning a satellite bestows far more prestige on a nation than does leasing services from Intelsat, as these countries are discovering.

This upsurge of interest in satellites reflects their usefulness in allowing a country to bypass more expensive communications technology. Intelsat has been besieged with developing countries' requests for transponders for domestic telephone-service use. The number of developing countries leasing circuits from Intelsat

for domestic telephones has grown from two in 1974 to 24 in 1983; Intelsat expects that number to reach 54 by 1985 [Fig. 2].

In the past, Intelsat has offered such service only when it has had satellite capacity left unused from heavily trafficked international communication routes. Thus, demand has been exceeding supply, and some developing countries are making plans for buying their own satellites for regional and domestic communications.

For example, Indonesia, the first developing country to own communications satellites, decided to buy a satellite from the United States and have NASA launch it because "our demands are too big for Intelsat," said R. Sunaryo, head of the Indonesian National Institute of Aerospace and Space.

When formed in 1964, Intelsat had 16 participating countries, each owning a share based on its use of the network; however, the United States, as a major user, owned 63 percent. "It was a *de facto* U.S. monopoly, and it was forced on the rest of the world because the United States had all the technology and the Europeans wanted it," according to John Logsdon, who holds the Chair in Space History at the National Air and Space Museum, Washington, D.C.

Modifications to the Intelsat agreements occurred from 1969 to 1971, when the growing participation of developing countries led to a policy more conducive to equal representation of all members. Most of Intelsat's business still goes to U.S. contractors, and over 50 percent of its staff are U.S. citizens, but the United States owns only 24 percent of the corporation. Though still the largest single share, new countries entering the organization promise to dilute U.S. ownership further. An article in the new convention clarified the conditions under which Intelsat members could approve other international commercial satellite systems. It stated that no other satellite system could be allowed unless it could be coordinated technically with the Intelsat network and it could be proved that it would not cause Intelsat "significant economic harm."

Some experts say Intelsat will have to adapt in coming years as more regional telecommunications systems spring up. "In five years, Intelsat will be a far different organization from what it is now," said Gordon Law, a consultant to the U.S. Congress Office of Technology in Washington, D.C.

The Indonesian, European, and Arab satellite networks have all been approved by Intelsat. In line with the demand for domestic service, Intelsat is considering plans to service more remote areas. "We will adapt to the new environment," said Joseph Pelton, executive assistant to the director of Intelsat, "by offering more kinds of service, by using smaller earth terminals

Space cooperation is sometimes a victim of budget cuts

Even the best international agreements for cooperation in space sometimes go awry for reasons unrelated to the interests of the agencies involved. One example is the International Solar Polar Mission.

This U.S.-European project was set up by the National Aeronautics and Space Administration and the European Space Agency in 1979. Two satellites—one made by NASA and the other made by the ESA—were to be launched by the U.S. Space Shuttle, fly past Jupiter, and then pass close to the sun on elliptical orbits. One satellite was to pass over the north pole of the sun, the other over the south pole. This way, scientists could use the two satellites with identical instruments to get a stereoscopic view of the sun.

Planning was proceeding nicely until NASA presented its fiscal year 1982 budget to the U.S. Office of Management and the Budget. The Reagan administration cut the project.

But the project survived, although only one satellite—the one made by the ESA—will make the trip past the sun. NASA will still provide a free launch and the tracking stations on the ground. All of the experiments originally planned will be carried out, though on one rather than two satellites.

One former NASA official said the Reagan administration was young, inexperienced, and understaffed and had simply made a mistake. Another said that NASA had submitted the solar-polar mission as a candidate to be cut in a gamble that the budget office would restore the program because it entailed a commitment to the ESA. Others say that the program would have been cut anyway because the Reagan administration proposed severe budget cuts to almost all parts of the Government that year.

—*F.G.*

for rural and business communications, and by improving our technology."

Developing versus developed power

Although the developing nations want space technologies and see them as essential to rapid development, they also want to avoid dependence on the more technologically advanced nations, and they want to place limits—through UN treaties and the pressure of world opinion—on how much those nations can exploit the developing countries.

At the Unispace '82 conference in Vienna, developing nations expressed concern over three key technologies: remote sensing, access to geostationary orbits, and direct-broadcast satellites.

Geostationary orbit, some 22 000 miles above the equator, is attractive for communications satellites because there they orbit at the same rate as the earth revolves and thus remain in a fixed location in relation to the earth's surface. Receiving and transmitting stations on the ground need only point in a single direction all the time. But the arc of these orbits is becoming overcrowded. Despite assurance from the United States and other developed countries that technological advances will alleviate the overcrowding, the developing countries fear being shut out of the telecommunications business. Unless curtailed by treaty, they contend, the industrial nations will use up all of the available slots before the developing nations can build their own satellites.

In 1977, the countries of the UN International Telecommunications Union, which includes almost all UN members, met at the World Administrative Radio Conference (WARC) in Geneva to divide the equatorial orbital arc for the K-band broadcast frequency used for direct-broadcast satellites. Although no such satellites were being used then by any nation, each ITU country, except those in North or South America, was assigned its own slot, regardless of whether or not it had plans for using the slot. The Americas decided among themselves last July in the Regional Administrative Radio Conference in Geneva how to divide the remaining slots.

These agreements on orbital slots are similar to the Law of the Seas Treaty, in that they would create a mechanism for dividing a limited natural resource among all nations, whether or not they made any investment to obtain or use the resource, according to S. Neil Hosenball, chief counsel for NASA. The 1982 Law of the Seas Treaty, which the United States and a handful of other industrialized countries refused to sign, created an international enterprise through which any profits from mining deep under the oceans would be distributed equally to the developing countries. The prior assignment of orbital slots may make it necessary for developed countries that want to expand satellite capacity beyond their allotments to rent the orbital slots from developing or neighboring countries. Whether or not slots from one region could be leased to serve another region is unresolved.

Other WARC meetings are planned for 1985 and 1988, in which the assigning of orbital slots for all types of communications will be discussed. Currently, the K band (14 gigahertz on the up link, 11 on the down link) is not used extensively, and thus the assignment of orbital slots corresponding to the K band occurred while the slots still were available. But the C band (6/4 GHz) is becoming crowded. Developing countries want the developed nations to switch to higher-frequency bands for communication and leave more of the C band, which requires less expensive communications technology, for them. Currently, the C band accounts for about 90 percent of all communications.

The United States disagrees with the other countries of North and South America on whether orbital overcrowding will keep developing countries out of the telecommunications business. U.S. critics of the ITU agreements said that technological advances will make it cheaper to pack more communications channels into a smaller bandwidth, as well as to construct space platforms to alleviate orbital crowding.

Communications technology has a history of using higher fre-

II. Selected future projects of non-U.S. space powers

CANADA

1988 Mobile-communications satellite (MSAT), for mobile and remote users.

1990 Synthetic-aperture radar satellite (Radarsat) for remote sensing through cloud cover and at night.

CHINA

1984 CZ-3 launching vehicle capable of putting payloads into geostationary or sun-synchronous orbit. Communications satellite, STW-2, and meteorological satellite to be deployed by CZ-3.

EUROPEAN SPACE AGENCY

1984 Maritime communications satellite, Marecs-B2, to be deployed by Ariane.

1985 Halley's Comet observatory satellite, Giotto, to be deployed by Ariane.

1988 Large communications satellite, Olympus (formerly called LSAT), to be deployed by Ariane. International Solar Polar Mission (ISPM) satellite and space telescope with ESA-built faint-object camera to be deployed by shuttle.

1987 European remote-sensing satellite (ERS-1) to be deployed by Ariane.

1988 Astronomical surveying satellite, Hipparcos, to be deployed by Ariane.

1988 to 1990 Infrared space observatory (ISO).

FRANCE

1-4B Remote-sensing satellite, SPOT; communications satellite, Telecom-1; and direct-broadcast television satellite, TDF-1, to be deployed by Ariane.

1986 Ariane 4 series launching vehicles to be deployed.

GREAT BRITAIN

1985 Military communications satellite, Skynet IV, to be deployed by shuttle.

1988 Olympus, primarily British-built, and direct-broadcast television satellite, Unisat-1, to be deployed by Ariane.

INDIA

1984 Indian remote-sensing (IRS) satellite to be deployed by USSR. Indian cosmonaut to join Soviet team on Salyut 7 space station.

1986 to 1987 Polar satellite launching vehicle (PSLV), capable of putting 1000-kilogram payload into sun-synchronous orbit, to be deployed.

Indian communications satellite (Insat) to be deployed by shuttle.

JAPAN

1984 Communications satellite, Sakura-2A, and geostationary meteorological satellite (GMS-3), to be deployed by Japanese N-series boosters.

1986 Halley's Comet observatory satellite, Planet-A, and heliocentric sun observatory satellite, MS-T5.

1986 to 1987 Marine-observation satellite (MOS).

1988 to 1988 Earth-resources satellite.

USSR

1988 Venus–Halley's Comet spacecraft, joint project with France, will drop probe onto Venus, rendezvous with comet in 1986.

1986 to 1987 Deployment of space station to succeed Salyut.

Tentative plans Construction of space shuttle. Manned mission to Mars.

WEST GERMANY

1985 U.S. Space Shuttle–Spacelab mission, D-1, devoted to German experiments.

1987 X-ray telescope satellite, Roast, joint project with Great Britain and the United States, and Jupiter orbiter-probe, Galileo, joint project with the United States, to be deployed by shuttle.

quencies to fit more signals into a crowded bandwidth, said John McLucas, president of Comsat World Systems. "You will find you can reuse existing frequencies more often than you thought you could, narrow the spot size of beams, stack satellites closer together, and get more mileage out of the existing spectrum," he noted.

Developing nations are worried that using the higher frequencies will require money and expertise which they lack. For example, Dr. Sunaryo, head of the Indonesian space program, told *Spectrum* he is concerned that developed countries will overcrowd the lower-frequency orbital slots, forcing Indonesia to use the more sophisticated—and expensive—technology for the higher-frequency slots.

Aside from the greater expense, developing countries also have expressed concern that sophisticated technology is difficult to maintain in countries such as Indonesia, which is largely agricultural. "We don't have the manpower for all the systems we'd like to have," said Mr. Law, the Office of Technology Assessment consultant in Washington, D.C. "If we don't, with our educational system, what chance do developing countries have?"

In proposing solutions to the overcrowding problem, people in the United States tend to think of technological development in terms of what is suitable for their own country, noted Ray Williamson, a project director at OTA. For example, "One engineer painted a whole scenario of how fiber optics would force down the price of satellites, except that he didn't realize that fiber optics is not an option for many developing countries because it doesn't fit into their infrastructure," he said.

Earth satellites at issue

Another area of dissent between developing and developed nations involves how best to share the fruits of space applications. The Landsat satellites, for example, have been providing information about countries that often cannot be obtained as cheaply in any other way. Current U.S. policy is to sell Landsat data without discrimination to anyone who wants them—an equitable policy, except that developing countries say they do not have the capabilities to process or interpret the data. They fear exploitation by organizations that have the computers and expertise to do the job. For example, commodities traders might use early estimates of foreign crop yields to manipulate markets. For this reason, a group of 77 developing countries at Unispace questioned the right of the United States to disseminate Landsat data about one country to other countries.

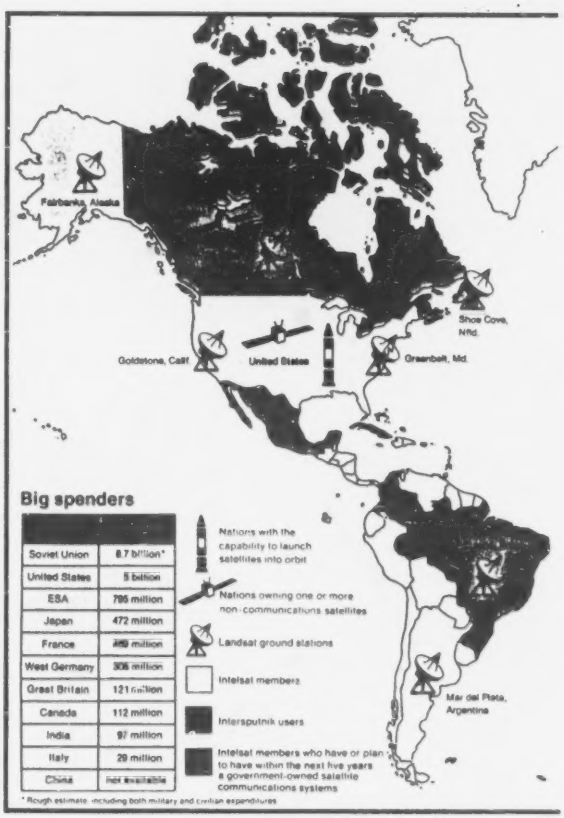
The National Oceanic and Atmospheric Administration, which is currently responsible for Landsat, offers the information at a set, subsidized rate to all nations. In addition, the U.S. Advanced Information Development Program teaches people in Kenya, Upper Volta, and Thailand how to use Landsat data.

As for direct-broadcast satellites, with their potential not only for educational television, but also advertising and commercial television, the Soviet-bloc countries fear propaganda from the West, the French fear a degradation of quality in programming, and Indonesia fears its people will learn to desire luxuries they cannot afford.

Many nations want a UN treaty requiring a foreign entity, such as a broadcasting network, to obtain the permission of a country before signals from a direct-broadcast satellite service can be received in that country. The Soviet Union has voiced particular concern over this issue. The General Assembly of the UN adopted a resolution, in December 1982, calling for "consultation and agreement" if one country's broadcasts will spill over unintentionally into another's, but the resolution is not legally binding.

Outlook for cooperation

The prospects for future cooperative ventures among the developed countries appear bright [see Table II]. NASA is planning joint projects with Canada, several European countries, Japan, and others. France is planning joint projects with the Soviet Union and is cooperating with India on its space program. The


Fairbanks, Alaska
Goldstone, Calif.
United States
Shoe Cove, Nfld.
Greenbelt, Md.
Mar del Plata, Argentina
Nations with the capability to launch satellites into orbit
Nations owning one or more non-communications satellites
Landsat ground stations
Intelsat members
Intersputnik users
Intelsat members who have or plan to have within the next five years a government-owned satellite communications systems

Big spenders

Soviet Union	8.7 billion*
United States	5 billion
ESA	795 million
Japan	472 million
France	469 million
West Germany	306 million
Great Britain	121 million
Canada	112 million
India	97 million
Italy	29 million
China	not available

* Rough estimate, including both military and civilian expenditures

[R] International cooperation in communications takes place mainly through the Intelsat and Intersputnik networks. Regional and domestic systems, however, are springing up to supplement the Intelsat service. The map indicates those governments who own non-communications satellites and launchers; the table (left) further differentiates among these wealthier space powers. (Note: the United States was not counted among those countries with government-owned systems, because U.S. communication systems are primarily privately owned.)

Infrared Astronomy Satellite, a U.S.–British–Dutch observatory launched last January, is an example of a successful joint mission. It has discovered comets and other phenomena by detecting their infrared radiation. Last month the satellite uncovered the first substantial evidence of a planetary system other than our own—orbiting Vega, a star 26 light years from the earth.

Some diplomatic wrinkles will need ironing out for future projects, however. For example, in projects with NASA, France wants more input at the planning stages than it had in the Spacelab project. Hubert Curien, president of the Centre National d'Etudes Spatiales, the French national space agency, said that NASA approached Europe long after its post-Apollo plans had solidified. "It's not the same being invited to a mission and being a father of a mission," he said. "But from time to time, it would be rewarding for French or European scientists to be involved from the very beginning in the definition of a mission."

Mr. Beggs, the NASA administrator, is sympathetic to Mr. Curien's view. "We have in most cases waited until we had a program committed . . . before we invited them to take part," he conceded. "But in the case of the [proposed] space station, we invited the Europeans, the Canadians, and the Japanese to participate in our studies."

Although cooperation between the United States and the Soviet Union is at a low, the two superpowers have been exchanging data. "The Soviets have given us some biological and physiological data on their manned flights that have been extremely useful in assessing the effect of long-duration weightlessness in flights," said Mr. Beggs. "Also, we're assisting France in designing an instrument on its upcoming Venus mission," he added. "What the Soviets don't tell us is what they're doing out there, the specific experiments, whether they are involved in any specific work that is related to anything we have in mind for the future."

In the United Nations, the military presence in space promises

to remain at the forefront of debate. Military involvement in space is the most threatening and important issue concerning future international cooperation, especially with the developing countries, according to Marvin Robinson, who retired last May as head of the UN outer-space division.

Nevertheless, the military issue will remain. The U.S. delegation to Unispace '82 almost walked out of the conference because many developing countries wanted to discuss the threat of militarization on international affairs, according to a member of the U.S. delegation. The U.S. policy is to debate the issue only in arms-limitation talks, to prevent the technical issues concerning space from being eclipsed by the military issues at conferences such as Unispace. ◆

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COMMERCIALIZATION: HIGH TIME FOR PROFITS?

From the outset, proponents of space exploration have argued that it is justified because of its enhancement of national security, contribution to basic scientific knowledge, and potential for economic gain. Without reconnaisance satellites, they say, international tensions would mount. Scientists point to multitudes of discoveries about the universe, the solar system, the moon, the earth, and the human body that have resulted from space programs. But outside of communications, little economic gain has been realized directly from the first 25 years of space activity.

That situation is changing. The United States government monopoly on space launching is ending, and companies like General Dynamics Convair Division in San Diego, Calif., and Federal Express, along with new ventures, such as Space Services Inc. of Houston, Texas, and Starstruck Inc. of Redwood City, Calif., are preparing to compete for a share of the business. Arianespace in France is already marketing a rocket. Estimates by these potential competitors indicate that commercial space-launching revenues could total $6 billion through 1991.

The U.S. Government has also indicated that it intends to stop making data from remote-sensing satellites available for nominal fees, and companies like Spot-Image SA in France, American Science Technology Corp., and Terremar Inc. are preparing to send up their own satellites to gather data for map making, crop monitoring, and mineral-resource assessment and to sell that information for a profit.

Tekla S. Perry Associate Editor

Space Services Inc.

McDonnell Douglas Corp. and Johnson & Johnson have demonstrated in space a manufacturing process for pharmaceuticals that they hope will be ready to make drugs for clinical testing in 1985. And other companies are planning the manufacture of gallium arsenide crystals and alloyed metals in space in the late 1980s.

A need for high finances and low risk

This spurt of interest in commercial space activity seems slow in coming. Remote-sensing satellites—operated in space before communications satellites were even tested in geosynchronous orbit—and launching technology have been mature for years, yet the commercial sector stayed out of these businesses while it put the communications satellite business into the black in 1968 and then expanded it to its current annual revenues of $2.5 billion. If space as a high-technology industry has a potential for big payoffs, why have entrepreneurs and venture capitalists shunned it for so long?

For one thing, space ventures have much higher capital needs than other high-technology industries. "You don't come in as a financing institution and take a flier," said Jerry Simonoff, vice president of Citicorp Industrial Credit Inc. of Harrison, N.Y., and few entrepreneurs can afford to finance such expensive endeavors out of their own pockets.

Difficulty in attracting investors, however, is not the only reason not all sectors of the space business have been booming. The answer lies in the infrastructures surrounding the technologies. As a train engine cannot operate profitably unless it is integrated with a rail system and can reach its customers at convenient stations, space ventures need to be able to deliver their products to an established market.

Communications, as an industry, has existed for 100 years, nationally and internationally, going back to the telegraph. It has over the years developed a price structure and a network of users. Communications satellites, as a new technology, have been able to plug into that network, increasing its capabilities and decreasing costs without changing much at the customer's end. The industry has also consolidated into a few very large private companies and government concerns serving a defined market.

Remote sensing, as an industry, has also been in existence for some time. People throughout the country have come to rely on weather data supplied by U.S. government satellites. This market is aggregated

[1] In September 1982, the expendable launch vehicle Conestoga was launched from a private ranch on Matagorda Island, Texas, by Space Services Inc. of Houston. Though only a test launch, it marked the entry of the private sector into the space launch business. SSI will follow this test with a commercial launch in 1985.

and large. However, it is not a true market because the Government has been supplying the weather data free, as a public service, and it would be difficult to make users now pay for this information.

Another potential market for remote-sensing satellites is aerial surveying to assess mineral resources, check timber growth, or improve map making. The market has a well-defined price structure, but it is very difficult to plug into. When communications satellites were developed, the few but wealthy potential customers could guarantee a market in themselves. Already buying remote-sensed data from local pilots are many small potential users who would be difficult to aggregate into a satellite market.

The barrier to launching services has been slightly different. The communications companies made a clear market and facilities such as launcher production lines and launching pads have multiplied as space activity has grown. These facilities, however, have not been available for commercial use: the Government controlled them and had a monopoly on space-rocket launching until the European Space Agency (ESA) developed its own launcher, the Ariane, and established a commercial company to market it worldwide. Now even the Soviets have indicated an interest in the commercial launch business, entering the Proton rocket in the competition for the business, and private U.S. companies are getting ready to compete.

Billions in launching revenues foreseen

Launching services will be needed for approximately 245 commercial satellites between 1986 and 1995, with potential revenue of $10 billion over this period, predicted William F. Rector III, vice president of space programs for General Dynamics. There is a potential market for 180 satellites that can be launched at an average of $30 million per satellite between 1985 and 1991, according to the French company Arianespace.

General Dynamics and Arianespace are only two of the many private companies that may compete with the National Aeronautics and Space Administration (NASA) for the business of launching satellites into orbit over the next few years. The projections of these two companies are based on proposed communications satellites; the market may be bigger than predicted if other commercial space ventures take off.

Arianespace, the first commercial competitor to the U.S. government launching services, was incorporated in 1980 as a private company in France. It is partly owned by the French national space agency, but the majority of the company is held by aerospace companies and banks throughout Europe. Starting next year, Arianespace will produce, finance, market, and launch Ariane expendable launching vehicles.

With the U.S. government's monopoly broken, President Ronald Reagan announced this May that the U.S. government was giving up its control of the launching of expendable rockets and that those companies that had been manufacturing the rockets or other private companies could buy parts and Government-owned plans for the launchers at cost and use Government launching pads and personnel for a fee. The manufacturers had been testifying in Washington for months in favor of such a policy. They were careful to present their pro-

Private launchings face regulatory unknown

Now that Space Services Inc. of Houston, Texas, has proved with a suborbital test launching that getting a satellite into space does not require government personnel or launching facilities, and other companies are proposing independent launchings, new regulatory methods must be found if governments are to keep control of space activity. Space Services had to cross uncharted regulatory territory that could easily have delayed or canceled its test launching from Matagorda Island off Texas, in 1982. (An earlier attempt by the company to launch a rocket in 1981 failed when the rocket blew up on the launching platform.)

Charles Chafer, Space Service's vice president of government affairs, describes the company's experience:

"For our first test launch, regulation was minimal, because no one had thought much about it. The next time we planned a test launch there was an interagency group put together to determine a regulatory scheme. It decided we needed FCC clearance, so we got an experimental radio license for the command-destruct telemetry. From the Federal Aviation Administration we had to get an exemption.

"The exemption required two Federal Register notices with public comments. We got an export license from the State Department. It's hard to see what we exported, but they said that under the 1967 treaty they had responsibility to supervise our activities and they needed some mechanism to approve us, so they decided on an export license under the munitions control act. We got that the day before the launch. "We also got a gun dealer's license from the Bureau of Alcoholic Beverages and Firearms, because we used artillery rockets to calibrate our radar. Because we purchased the motor from NASA, it imposed a liability insurance requirement on us.

"Then we had a series of informal arrangements with the Coast Guard and the Navy, because we were launching near an air-training center, and with Norad. Norad said it didn't have the authority to make us cooperate with it, but would we please keep a line into them so we wouldn't hit any low-flying satellites. We weren't ever officially informed by anybody about all the things we had to do."

None of these regulatory bodies, however, gave the Space Services project any kind of technical review. The Government is leaving that to the insurance industry. For the company's test project, the National Aeronautics and Space Administration demanded that Space Services obtain liability insurance. Once the company is ready to operate commercially, the customers will require a guarantee, that they will get their money back if for example—as happened on a recent Ariane launching—the launcher fails and dumps its payload into the ocean.

Stated Brian Hughes, a staff member of the U.S. Aircraft Insurance Group, a consortium of 15 major U.S. insurance companies and the first insurer to offer space coverage with a policy on the 1965 Earlybird communications satellite, "We will insure anything flying, with different premiums, depending on the history of the vehicle." Under that guideline, the expendable launchers being commercialized now in the United States, all with excellent records, will qualify for the lowest insurance rates; Ariane, with a shorter history and a greater percentage of failures, will qualify for higher rates; and Space Service's newest launcher for slightly higher. The judgment of the insurers, however, is not perfect—from 1978 to 1982, Mr. Hughes said, $1.6 billion in damage insurance was purchased for space ventures, with the insurers receiving, after commissions, $100 million in premiums and paying losses of $184 million.

The U.S. Government says that the Space Services launching was a learning process for the Federal agencies, and now an interagency group is trying to figure out what the licensing process should be. One agency noticeably missing from the list of permission granters is NASA, and the space agency's administrator, James Beggs, said that is the way it should be.

"I don't want NASA doing it," he said. "NASA is not in the regulation business: we are a research and development agency. Some other agency should be doing that. Since a number of different agencies and departments are involved, there should be a single point of coordination. Our hope is to find some agency that will take on that chore." —*T.S.P.*

Space technology spins off benefits

More than 3500 inventions that can be applied on Earth are available for licensing as a result of spinoffs from the U.S. space program. Under the 1958 legislation that created the National Aeronautics and Space Administration, the agency is required to disseminate to the public any technology it develops. The methods it uses include a quarterly publication listing new technologies available for transfer, various applications centers at which NASA engineers are available to help industry apply space technology, a computerized information-retrieval system, and programs that allow representatives of industry to visit NASA facilities.

These efforts have transferred much technology developed for use in space to the private sector, where it has found new commercial uses. As an example of how the process works, Ronald Philips, NASA's director of technology use and industry affairs, described a technique picked up by John Deere & Co. of Moline, Ill.

"John Deere builds heavy equipment," he noted. "One of the continuous problems was that where the tracks on their tracked vehicles connect, they wear out easily and must be replaced often. On a visit to our Langley [Hampton, Va.] and Lewis [Cleveland, Ohio] research centers, at which our scientists and engineers give presentations about ongoing projects, Deere discovered a technology that, developed by discussions with people in our laboratories and reading of our publications, let the company make a new device for the bonding of tracks together. It has a much longer life and provides significant savings for customers."

Other examples of successful technology transfer include:

- Programmable implantable medication systems that dispense measured amounts of drugs, like insulin. These arose from technology developed for the Viking missions to Mars, in which fluid controls to meter the nutrients in soil samples were miniaturized.
- Lightweight material weighing half as much as aluminum that can be used in leg braces and walkers for handicapped people.
- A fabric designed for astronaut space suits that has proved suitable for architectural applications. The fabric, a glass-fiber yarn coated with Teflon, has been used, for example, to roof an airport terminal near Mecca in Saudi Arabia, a department store in California, and the Silverdome stadium in Pontiac, Mich.
- Sportswear that removes heat by using a spinoff from the liquid cooling systems in astronaut space suits. The sportswear contains gel packets that absorb heat.
- Gortex, a lightweight heat-protective material for firefighters developed originally for astronaut space suits. The material is completely waterproof but allows moisture, vapor, and body heat to escape. It is also being used in ski clothing.
- A duck inventory being taken in North America by a nonprofit group that is using Landsat data.

—*T.S.P.*

posed ventures not as competition to the U.S. Space Shuttle, but as a complementary backup. Mr. Rector of General Dynamics said in testimony before a House committee:

"Ariane should not be allowed to take over the ELV [expendable launch vehicle] business unchallenged. Commercializing today's proven U.S. ELVs will provide a capability to accommodate the overflow in launch requirements in direct competition with Ariane."

Those operating the shuttle program agree that the private expendable rockets will complement rather than compete with the shuttle. General James A. Abrahamson, head of the shuttle program for NASA, said the expendable launch vehicles that survive will not compete with the shuttle but will offer special services in, for example, launching very small satellites or targeting satellites to special, nongeosynchronous orbits, and the larger, more complex orbital systems will be carried aloft by the shuttle. (This appears to be a change in NASA's stance, which originally leaned toward the phasing out of ELVs to remove competition for the shuttle.) At this writing, the Government had not released specifics on how it would make its launching sites and services available. A task force, led by the Department of State and NASA, has been set up to develop the implementation plan.

Waiting for the task force's conclusions are Federal Express, which has announced plans to commercialize Martin Marietta's rockets; General Dynamics, which will launch its own rockets; and Transpace Carriers Inc. of Washington, D.C., which plans to market and launch rockets made by McDonnell Douglas. And new players are springing up.

One company has already been successful without launching a rocket. Before the Government policy was announced, Klaus Heiss, former president of SpaceTran Inc. of Princeton, N.J., signed agreements with Martin Marietta and the other companies for commercial manufacture of the Titan rocket, with the agreement to become moot if the Government failed to act. After the Government's policy announcement in May, SpaceTran agreed to transfer its name, the agreements, and market studies and proposals to Federal Express. T. Allan McArtor, president of Fedex SpaceTran, the new Federal Express subsidiary, said that no money has changed hands and the companies are studying continued partnerships. Dr. Heiss indicated that "the agreed-upon payments are substantial."

Federal Express and its Fedex SpaceTran were welcomed by other companies entering the space-transportation business. The participation of such an established company places a stamp of approval on the fledgeling industry.

"I hope they paint the Federal Express logo on a rocket," Dr. Heiss said. "A rocket should have all the emblems—from STP, to diapers, to Coca Cola. Nothing looks better than an American racing car at Indianapolis with all those decals on it. When you see those decals on an American rocket launcher, you know that space is here to stay."

Some entrepreneurs did not wait for the Government to make the launching vehicles available but set out to develop their own. This became possible, noted Charles Chafer, vice president for government affairs of Space Services Inc., because "current breakthroughs in computer chips mean satellites do not have to be 18-foot Landsat buses that you send up on a Delta rocket or a shuttle, but rather they can resemble a breadbox—which means a lightweight satellite, a smaller launch vehicle, and much lower costs."

Space Services is trying to build that smaller launching vehicle. It is not intended to compete with the shuttle or Ariane or existing vehicles; it is being designed for lightweight, low-earth-orbit launches. The company has test-fired two rockets—the Percheron, which blew up on the launching pad, and the Conestoga [see Fig. 1, p. 49], which made a suborbital flight—and it plans its first commercial launching in mid-1985.

Another type of expendable launch vehicle is under development by Starstruck Inc. Roy McDonald, the company's director of public information, said that Space Services is using existing propulsion systems for its launcher, whereas Starstruck is developing a hybrid propulsion system that uses a solid fuel and a liquid oxidizer in the same motor. The company has decided not to buy an existing launching rocket, Mr. McDonald said, because, "while they are all good rockets, they are awfully expensive. We

are taking a purely private-sector approach, being ruthless on simplicity to increase reliability and cost-effectiveness."

The private sector is not ignoring the commercial possiblities of NASA's space shuttle. In fact, some entrepreneurs want to get their hands on one. Dr. Heiss, who founded SpaceTran, put together a group of investors who are interested in financing the construction and operation of a fifth shuttle. He has been pursuing this proposal for four years now, but the Government is undecided whether to allow private funding.

One problem independent companies have is obtaining permission from various Government agencies to launch a rocket, as the regulatory process is still poorly defined [see "Private launchings face regulatory unknown," p. 50]. However, the Government has established an interagency working group that will, the companies hope, straighten out the regulatory tangle before long. Uncertainty in regulation adds risk.

As more companies enter the launching business, the price of services seems likely to fall. Though the companies will compete initially for the communications industry's business, their presence seems destined to open up space to other commercial ventures. Space-transportation companies are admittedly counting on this growth in the market for part of their business, but they are not making their projections public.

Remote sensing: an uncertain market

Remote sensing, or using satellites to observe the land, water, or cloud cover, has been proved technically feasible and widely useful. In 1960 the United States launched the Tiros 1 weather satellite to begin routine observations of the earth's atmosphere. In 1972 the first earth-resources satellite, later called Landsat-1, was launched, followed by a series of more sophisticated Landsat models. No space company questions that data from remote sensing are valuable, but until now none has tried to put a real price on it, since the Government has been operating the weather- and land-observation systems as a public service.

But now a French company that plans to operate a commercial remote-sensing system is estimating that the return will at least equal operating costs of $400 million over 10 years, and two companies in the United States are also banking on a large market for remote sensing that they can profit from if the U.S. government stops giving away the information. The Government has said it will halt this practice. The Administration has decided that Landsat is to be transferred to the private sector or closed down by 1988. But the private sector may not want to take over Landsat. Though the technology may be ready for commercialization, most entrepreneurs think Landsat as a system is not. Designed as a research tool, it is very complex, with numerous capabilities—a Cadillac when users can only afford a Volkswagen.

The American Science and Technology Corp. of Bethesda, Md., is developing a low-cost remote-sensing satellite in a joint venture with Space Services Inc. The satellite is planned as Space Service's first commercial launching in 1985.

Terre-Mar Inc. of Mountain View, Calif., is also planning to commercialize remote sensing with its own system if Landsat is withdrawn. Don Walklet, president of the company, said that the next-generation system should be more cost-effective. Present costs for Landsat, he said, are too high to make a profit for a business. "It's quite unfair for the Government to think that we can afford Landsat without them giving it away," he said. "It is obsolete technology, complicated, and vulnerable to failure."

Before asking for bids from the private sector for Landsat, the Government asked for information informally in 1982. It got a response from Comsat. The communications consortium said it would buy the Landsat system if it was packaged with the weather-satellite system and the Government guaranteed the purchase of weather information. John L. McLucas, president of Comsat's World Systems Division, said, "I doubt I can predict that Landsat will ever go commercial in the normal sense. It has utility, but I don't know if it has enough utility to be commercial. Only weather information has such a huge demand, and then it's not commercialization in the usual sense, just a contract with the Government to supply the data."

Mr. Chafer of Space Services said, "Weather is irrelevant. It's just a way to get a Government subsidy, and we're not interested in that business."

Comsat is wary about going into the remote-sensing business without Government guarantees, because no one is sure how big the business might be. For the price of an earth station, which is somewhat expensive, plus annual royalties, or by purchasing data from the U.S. Eros Data Center, Landsat data are available to anyone in any country for use in map making, monitoring crops, detecting large schools of fish, making land-use assessments, and exploring nonrenewable resources.

While NASA developed a number of users of the Landsat data before turning the system over to the National Oceanographic and Atmospheric Administration (NOAA) to operate, the Government is not a marketing organization, and no real effort has been made to encourage people to ask for the data. Moreover, the existing users are not true customers, for they pay nowhere near the cost of producing the data.

Mr. Chafer, however, is enthusiastic about the commercial possibilities. "There is a huge market for data, but it's all potential," he said. "The Government has always said, 'Here's what we've got, folks. Come and buy it if you want it.' Even with that approach, there are an amazing number of ground stations and data purchases, but to be a business you have to market it."

Meanwhile the French company Spot-Image SA of Toulouse, a private company created to market data from remote-sensing satellites that have been developed, launched, and operated by the French national space agency, is moving ahead with its plans. In January 1985, whether or not the U.S. government continues to operate Landsat, the first SPOT satellite will be launched.

It was developed, said Gilbert Weill, president of the Spot-Image Corp. of Washington, D.C., the U.S. marketing arm, because many groups in Europe have been intrigued by the Landsat data but also have been frustrated. Europe has smaller fields for agriculture and smaller parcels of land in general than the United States, so Landsat's resolution has been inadequate for many applications in Europe [see photo]. The SPOT satellite is to have substantially greater resolution, as much as 10 by 10 meters per pixel compared with Landsat's 56-by-79-meter multispectral scanner resolution. (The Landsat thematic mapper, which has had operating difficulties, has a 30-by-30-meter resolution.)

To deal with the increased resolution in terms of data transmission and processing, the width of the scan is smaller for SPOT—60 kilometers versus Landsat's 185. SPOT, however, has a pointable mirror that allows several repeated scans of an area instead of a scan every few weeks—important in monitoring changes in the environment—and it also permits the construction of three-dimensional images with a technique that scans the same area twice from different angles. The 3-D approach is important for the assessment of mineral resources and for use in map making.

Manufacturing in space undergoing tests

When space-based manufacturing is considered in the United States, Government officials discuss it as an industry about to take off. "Why, take that McDonnell Douglas and Johnson & Johnson joint venture, for example," runs a typical comment.

"They'll be manufacturing drugs in space in a year or two. Oh, they'll have to get Federal Drug Administration approvals and all that, but pretty soon . . ."

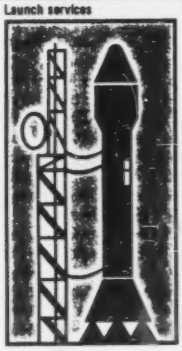
McDonnell Douglas and Johnson & Johnson are using a process called electrophoresis to manufacture pharmaceuticals. Electrophoresis separates materials in a solution by subjecting them to an electric field. In a continuous-flow process, a stream of biological materials is injected into a solution flowing through a thin, rectangular chamber. The application of the electric field pulls the materials into separate streams, which flow out of the top of the chamber and are collected in separate tubes.

In gravity, the biological material will sink to the bottom of the chamber if it is heavier than the solution it is flowing through; therefore extremely low concentrations have to be used, limiting the amount of the sample that can be processed. Also, there are convection currents in a gravity environment, because of heating from the electric field, and these cause the particle streams to waver and exit through each other's outlets, thereby reducing purity. These and other gravity-caused problems are removed when the tests are conducted in space.

The space experiments conducted on shuttle flights proved that the amount of material separated can be increased nearly 500 times at purity levels four times higher. A production prototype of an electrophoresis system is being produced, to be flown on the shuttle in 1985. This is expected to manufacture enough material for a clinical trial. After that the company plans to seek FDA approval and to fly production electrophoresis units as shuttle payloads. Exactly what the company will be producing is a trade secret, but possibilities include an antihemophilic factor and also a possible cure for diabetes called beta cells.

"I think that we're beginning to see quite a lot of entrepreneurial activity in that field, as people see that there's money to be made," said NASA Administrator James Beggs. "If the entrepreneurial spirit in this country still lives, and McDonnell Douglas and Johnson & Johnson make a commercial success out of electrophoresis and make profits, then other people are going to sit up and take notice and say, 'Hey, there's money to be made up there,' and they'll get involved."

Microgravity Research Associates of Coral Gables, Fla., has signed a joint agreement with NASA to commercialize crystal growth in space, and its first project will be gallium arsenide crystals for semiconductors. The company's president, Richard Randolph, explained, "We believe we will make a significant enhancement of crystal structure that would be important to the upper-end users for more sophisticated apparatus." The first space experiment with crystals is to take place in 1986.

Project	Who	What	Status
Launch services			
	Arianespace SA Evry, France	Ariane expendable launch vehicle	Takes over Ariane operation from European Space Agency in 1984
	Federal Express's Fedex Space-Tran Corp., Memphis, Tenn.	Titan, Delta, and Atlas–Centaur expendable launch vehicles	Expressed interest, plans being evaluated
	Space Services Inc. Houston, Texas	Expendable launch vehicle being designed for low-earth-orbit, lightweight satellites	Successfully tested model, plans commercial launch in 1985
	Starstruck Inc. Redwood City, Calif.	Developing hybrid propulsion system for water-launched expendable launch vehicle	Tested sounding rocket, continuing development, expects commercial operation in 1985
	Otrag West Germany	Developing solid-propellant expendable launch vehicles	Stalled because of launch-site difficulties
	Transpace Carriers Inc. Washington, D.C.	Delta ELV manufactured by McDonnell Douglas	Negotiating agreement with McDonnell Douglas
	Space Projects Inc. Princeton, N.J.	Fifth space shuttle	Has contacted financiers, submitted proposal to NASA
	TranSpace Inc. Washington, D.C.	Proposing "Spacevan"	Still trying to obtain funding, planning a public offering by year-end
	Orbital Systems Corp. Vienna, Va.	A privately funded upper stage for use on the shuttle	Financing obtained, NASA agreement signed, system being developed
	USSR	Proton expendable launch vehicle	Bidding on contract to launch second generation of Inmarsats beginning in 1985
	Computer Sciences Corp. Falls Church, Va.	Atlas–Centaur	Has expressed interest to NASA
Remote-sensing satellites			
	Comsat Corp. Washington, D.C.	Landsat system	Proposes purchasing Landsats from Government if weather system were included and Government made purchase guarantees
	Spot-Image SA Toulouse, France	Developing high-resolution satellite system	Will launch first satellite in 1985
	American Science & Technology Corp. Bethesda, Md.	Developing low-cost satellite system	Will launch first satellite in 1985
	Terra-Mar Inc. Mountain View, Calif.	Plans to develop low-cost system if Landsat stops operation	Waiting for Government to make a decision on Landsat
Manufacturing			
	McDonnell Douglas of St. Louis, Mo., and Johnson & Johnson of New Brunswick, N.J.	Pharmaceuticals by electrophoresis	Successful test completed, production prototype to fly in 1985
	Microgravity Research Associates Coral Gables, Fla.	Gallium arsenide crystal growth	Funding obtained, NASA agreement signed, first test scheduled for 1986
	GTI Corp. San Diego, Calif.	Alloy resolidification	Canceled program after market research showed lack of interest
	John Deere & Co. Moline, Ill.	Alloy processing	Signed technology exchange agreement with NASA for NASA flight of tests
Communications (new proposals)			
	Orion Corp., Washington, D.C.	Transatlantic satellite	Awaiting FCC action on proposal
	Inter-American Satellite Television Inc. Los Angeles, Calif.	Direct-broadcast satellite (DBS) transmission throughout U.S.	Announced agreement with Satellite Business Systems, financing provided by Rupert Murdoch, waiting for FCC action
	CBS Inc. New York, N.Y.	DBS to eastern time zone	Received conditional construction permit from FCC, awaiting slot assignment
	Direct Broadcast Satellite Corp. Washington, D.C.	DBS throughout U.S.	Received conditional construction permit from FCC, awaiting slot assignment
	Graphics Scanning Corp. Englewood, N.J.	DBS to western half of U.S.	Received conditional construction permit from FCC, awaiting slot assignment
	RCA American Communications Inc., Princeton, N.J.	DBS throughout U.S.	Received conditional construction permit from FCC, awaiting slot assignment
	U.S. Satellite Broadcasting Inc. St. Paul, Minn.	DBS throughout U.S.	Received conditional construction permit from FCC, awaiting slot assignment
	Video Satellite Systems Inc. Southfield, Mich.	DBS throughout U.S.	Received conditional construction permit from FCC, awaiting slot assignment
	Western Union Telegraph Co. Upper Saddle River, N.J.	DBS throughout U.S.	Received conditional construction permit from FCC, awaiting slot assignment
	Satellite Television Corp. (Comsat subsidiary), Washington, D.C.	DBS throughout U.S.	Received conditional construction permit from FCC, awaiting slot assignment

Morris Khan

John Deere & Co. of Moline, Ill., has signed a technical exchange agreement with NASA to study alloy processing in a low-gravity space environment, first using nonorbiting facilities, such as aircraft, and eventually using a space vehicle. And last year the GTI Corp. of San Diego, Calif., signed a joint agreement with NASA to perform low-gravity metallurgical research in space, but the company recently canceled this project, which was to design a multiuser furnace that would operate in space for use by the metals industry. GTI said that the technical goal of designing the furnace had been achieved but that the company had concluded that "there is not at this time enough industrial interest to carry on a profitable business."

Other products are thought to have potential for improvement through manufacturing in space, including alloyed metals, which could be strengthened through uniform blending, and glass, which could be purified, since it would not come into contact with a container and could be spun into high-performance optical fibers for earth communications.

Much research needs to be done, however. Before the advent of the space shuttle and regular flights into space, the opportunities for experimentation in a microgravity environment were limited, and though there were many ideas about how to use space—even given the limitation that because of the transportation costs the resulting product must be worth at least $5000 a pound—facilities to test those ideas are just now being set up.

The McDonnell Douglas experiments were among the first conducted according to a joint agreement with NASA, under which NASA flies the companies' experiments free and the companies finance the experiment itself.

Not all shuttle experiments go smoothly or yield the expected results. An experiment sent up by the Japanese to study crystallization in space surprised its designers. A machine that manufactures snow from water vapor on earth failed to manufacture snow in space—the machine apparently worked properly, but the water did not condense. This result shows clearly that much basic research needs to be done.

A time of change for commercial communications

The U.S. government, in the Communications Satellite Act of 1962, authorized the formation of Comsat to act as a commercial communications wholesaler in the United States and to represent U.S. interests internationally, but the deregulatory environment for telecommunications in the United States has led to a competitive environment involving many companies, including Western Union Co., ITT Corp., and AT&T Corp.

Even more companies are jumping into the fray, however, with the advent of direct-broadcast–satellite (DBS) technology, which would allow consumers to put small satellite dishes in their yards and receive broadcasts from satellites directly. If this concept takes off, it could lead to an astronomically increased demand for satellite space.

Internationally the satellite communications business has been conducted under a global cooperative, a monopoly that shows signs of disintegrating as a number of nations launch satellites for regional use. The International Telecommunications Satellite Consortium (Intelsat), a coalition of nations, had held control since its formation in 1964. The Intelsat agreements specify that satellites launched for domestic purposes must be technically coordinated with Intelsat and that satellites launched for international purposes must not economically harm Intelsat.

But there is a feeling in the United States that it may be time for Intelsat's monopoly to end. According to Dr. Heiss, formerly of SpaceTran, "Domestically deregulation has proved tremendously successful. The question has to be answered whether deregulation worldwide might reduce costs to the principal users, provide a greater variety of services, and hence expand the market. Why not give it a chance, in a controlled fashion?"

At a conference on satellites held last December in Washington, Andrea Caruso, secretary general of Eutelsat—a regional satellite system in Europe whose very existence appears to violate the Intelsat agreements, since Intelsat defines any satellite that serves more than one country as "international"—pointed out that economies of scale are down to zero due to the cost of operating such a large organization. Eutelsat and other groups that wish to put up regional satellites prefer not to rely on Intelsat in heavily traveled paths of communication. "They," said Ray Williamson of the U.S. Office of Technology Assessment, "want to buy a second car to commute in instead of taking the bus."

Ready to offer private users an alternative to Intelsat is Orion Corp. of Washington, D.C., which has proposed a satellite that would offer "private facilities" across the Atlantic. The company's president, Thomas K. McKnight, argues that private facilities do not compete with common-carrier facilities, for he is proposing to sell, not lease, transponders that could not be preempted by priority users on his satellite, so companies would not be dependent on a service they cannot control.

But Intelsat views Orion's proposal as a threat and is attempting to block it by protesting to the FCC, which must assign an orbital slot to Orion. Orion meanwhile is moving along with its plans, obtaining letters of support (but not firm commitments) from 20 potential users, including governments, on both sides of the Atlantic and holding a reservation for launching on the space shuttle in December 1986.

"When television came out, newspapers considered it a threat because it would take advertising away, but really it increased the market," Mr. McKnight said. "That is what we are talking about doing."

Blue-sky plans for space

Looking beyond the currently feasible possibilities for commercial exploitation of space, space-manufacturing proponents talk about mining asteroids for nonrenewable resources. Space is also being considered as a possible dump for nuclear wastes. Visionaries see future developments in communications technology leading to personal communications systems, like Dick Tracy–style wristwatch radios, holographic teleconferences, and crime prevention through the distribution of distress buttons that would signal a public-safety transceiver with the exact position of its wearer. The latter is being proposed to the FCC by the Geostar Corp. of Princeton, N.J.

Other envisioned schemes include solar-power satellites, which would be parked in orbit to collect energy from the sun and transmit it to earth. But controversy over potential environmental hazards and high costs has stalled serious consideration of this idea.

And what about a space-tourism industry? NASA has established a task force that is considering when extra room might be available on the shuttle and how often civilians might be invited to travel into space. The agency has even been approached by a potential travel agent to develop a "space shuttle passenger tour." It would carry 100 to 200 people a year into orbit, beginning around 1990, for $1 million per person.

Though many ideas for commercializing space will never be developed, others will. "Some projects are going to bomb," said Gen. Abrahamson of NASA, "but some are going to develop quite effectively. We will never be able to have the U.S. reach its full potential as a space power and fully utilize space unless we can bring the resources of private enterprise to bear." ◆

2. SPACE TECHNOLOGY

The Apollo program has been cited by leaders of Japan's fifth-generation computer project as a perfect model to illustrate how a focused technological project can yield broad benefits far beyond its own mission accomplishments. In fact, it can be argued that the U.S. space program spurred technological advancements in every nation on the globe. Certain advances were necessary to get missions off the ground, so to speak, but those improvements also enabled more sophisticated missions later on. At the same time, these and other triumphs improved the way technology was applied in the commercial sector.

The case studies and chart that follow are not intended as all-inclusive of their respective disciplines, but highlight selected work and some of the fallout over the last 25 years. They are largely U.S.-based, but similar examples exist in the Soviet program. As other nations become more involved in space, their societies, too, will benefit from the fallout of technology from their space research and development. How this fallout has benefited the technical community in the United States is examined in the first article in this section.

Key to the Apollo mission, the most extensive project of the U.S. space program, was the development of a guidance and navigation computer, which enabled astronauts Aldrin, Armstrong, and Collins to land on the moon. As explained in the second article, Apollo set new standards of reliability and accelerated developments in integrated circuits.

However, there is more to space than Apollo. The Landsat series improved technology for land, ocean, and atmospheric remote sensing. Landsat has had an international effect, too, motivating the French to develop SPOT, which will become the highest-resolution imaging system ever flown for civilian purposes when it is launched in 1985.

In each of several other areas of space technology, one event stands out as most noteworthy. In telecommunications, it was the successful launch and operation of the Syncom satellites in 1963. That system demonstrated the technical feasibility of geosynchronous communications and became a prototype for the Intelsat system. In solar-power supplies, a crucial component for most space missions, Skylab is seen as the outstanding model, supporting the largest and most complex photovoltaic array ever flown. Indeed, photovoltaic work throughout the world has been led by developments in space missions. In fireproofing spacecraft, one area of materials science, radical changes were made after a fire killed three Apollo astronauts. Another area of aerospace technology, displays and controls, has advanced due to technology transfer between designers of airplane cockpits and spacecraft crew stations.

Finally, the benefits of the world's space programs extend beyond specific technologies to the management of large, complex, and integrated engineering efforts. Space programs have helped advance the status of systems engineering and the "systems outlook" more than any large technology-driven program yet undertaken.

These points are underscored in the following articles.

APOLLO: THE DRIVER AND THE DRIVEN

The sheer scale of the United States endeavor to land a man on the moon spurred a sweeping drive of technologies that have since fluorished independently. And the technological fallout from 25 years in space has affected the way we develop and manage technology and integrate systems of hardware, software, and people.

The National Aeronautics and Space Administration anticipated the depth of the impact early in its program to explore space, giving a grant to the American Academy of Arts and Sciences to study the massive technological enterprise of the space effort for its effects on technological diffusion, community structure, manpower, and society. The first volume of the study appeared in 1965. At the time Raymond Bauer of the Harvard Business School, who headed the active working group of the academy's Committee on Space, observed that "the major diffusion of technological innovation is likely to take place after its period of maximum development when surplus technologists are freed to work in other sectors."

That may be where we stand now, at NASA's quarter-century mark, though the diffusion point was reached sooner than expected. Space programs have come and gone so quickly that they have made many engineers and other technologists available earlier to other areas of application. Today many of the architects and engineers of the space program occupy pivotal positions in industry and academia. They have transferred not only technical ideas, but also managerial innovation, especially in the area of integrating large-scale systems. When NASA geared up for the all-out Apollo effort, perhaps the most ambitious total system project ever attempted by a civilian team, it attracted the best and the brightest to its in-house work force and to its contractors. The Apollo program was an astonishingly complex combination of expedient engineering and hundreds of inventions yet to be made. All were tied to a rigorous timetable involving an enormous variety of contractors and subcontractors who were drawn from almost every technical field and discipline.

Evan Herbert Contributing Editor

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Because the Apollo program was tied to a clear national, albeit political, goal—beating the Soviets to the moon—NASA had several powerful factors in its favor. First, it was infused with almost limitless money, enabling it to enlarge its work force and to embark upon multiple approaches in solving problems. Up-front money also made it possible to support otherwise uneconomical development or manufacturing costs. For example, getting the high-reliability components for the Apollo guidance and navigation computer did not require major process innovation by the semiconductor industry; but the strict specifications for circuit reliability forced the setting up of multiple production lines and expensive quality-assurance programs.

Space-technology milestones

Spacecraft or satellite	Launch	Milestones
COMPUTERS		
Gemini 3	March 23, 1965	First on-board digital computer control. First glass delay-line registers and core main memory.
Gemini 8	March 16, 1966	First use of auxiliary storage in flight—a redundant three-track magnetic-tape unit read through voter circuits.
Apollo 4	Nov. 9, 1967	Saturn V launch-vehicle computer uses triple-redundancy and voter circuits to implement fault-tolerant approach to reliability.
Apollo 8	Dec. 21, 1968	On-board computer controls entire manned mission to circumnavigate moon.
STS-1[1]	April 12, 1981	Redundant five-computer, dual-tape memory system provides both aircraft and spacecraft control with fly-by-wire characteristics. First multiplexed data buses.
TELECOMMUNICATIONS		
Echo 1	Aug. 12, 1960	First passive communications satellite—a mylar balloon 30 meters in diameter.
Courier 1B	Oct. 4, 1960	First active-repeater orbited.Small signal loss but limited contact time. Ground stations had to track satellite.
Telstar 1	July 10, 1962	Demonstrated feasibility of wideband transoceanic communications via satellite.
Syncom 2	July 26, 1963	First communications satellite in synchronous orbit. No tracking needed and 24-hour access became available.
Early bird	April 6, 1965	First Intelsat satellite. First commercial communications made on June 8, 1965.
Communications Technology Satellite	Jan. 17, 1976	Pioneered use of Ku-band (12 to 18 GHz) in broadcast satellites. Extremely high antenna gain resulted in an effective isotropic-radiated power of 80 dBW, allowing use of earth receivers 40 cm in diameter. Prototype for direct-broadcast satellites. Joint project between Canada and the United States.
Marisat 1	Feb. 19, 1976	First maritime communications satellite. Signals could be received from and sent to moving ground stations on ships.
Direct broadcast Satellite	1984	First craft designed as a DBS will enable first entirely commercial communications satellite system. It will cover the entire United States.
Advance Communications Technology Satellite	1988	NASA satellite will receive and broadcast at 30 and 20 GHZ, respectively. Will have 18 fixed antennas, 6 multiple-spot beams, and on-board data processing and storage. Should increase capacity of present satellites by 100 times.
REMOTE SENSING		
Tiros 1	April 1, 1960	First satellite of NASA's earth-observation program took 22 952 surface photos.
Landsat 1	July 23, 1972	First earth-remote-sensing satellite. Spatial resolution was 80 meters.
SMS 8[2]	Feb. 8, 1975	First remote-sensing satellite in geosynchonous orbit and first one stabilized in three axes.
Seasat	June 26, 1978	First oceanographic remote-sensing satellite. Spaceborne synthetic-aperture radar proved useful for geological studies.
STS-2[1]	Nov. 12, 1981	Synthetic-aperture, or "imaging" radar, flown as a payload for the first time.
SPOT[3]	January 1985	Spaceborne sensors with the highest spatial resolution for nonmilitary uses is to be flown by France with Swedish and Belgian participation. Spatial resolution of 10 meters in black and white mode is expected.
SOLAR ARRAYS		
Vanguard 1	March 17, 1958	First photovoltaic-powered satellite.
Spaceflight 71-2	Oct. 3, 1972	First flexible-substrate photovoltaic array flown (by U.S. Air Force). Allowed large surface area to be rolled up into small stowage space. Rated at 1 kW.
Skylab	May 14, 1973	The largest photovoltaic power supply ever flown—21 kW. Power-to-mass ratio was 7 W/kg.
Hermes	Jan. 17, 1976	First photovoltaic cell array (1.3 kW) on a flexible substrate that folded like an accordian, decreasing weight as well as space. Flown by the European Space Agency.
Olympus platform	1988	First generic solar-powered platform. Multikilowatt flexible array (4 kW) will be flown by the European Space Agency and will carry communications satellites. Power-to-mass ratio will be 32 W/kg.

[1]Space Transportation System (space shuttle) [2]Synchronous Meteorological Satellite [3]Système Probatoire d'Observation de la Terre

A second factor aiding NASA was its firm, powerful control of the systems engineering process. Each of the development centers had a systems engineering division whose activities were integrated by a headquarters systems office. Moreover all NASA systems offices received additional technical support and advice from contract systems-engineering teams from companies like General Electric Co., Boeing Aircraft Co., and Bellcom (formed by AT&T to aid NASA). On questionable approaches it was possible to take multiple paths and to develop contingency plans for each risk.

A third factor in NASA's favor was the constant feedback to the Apollo systems-design engineers from astronauts and ground-support operators. This feedback had a major effect on software development and integration, which was recognized as so important to systems engineering that it was overseen from a single management viewpoint, that of the director of flight operations at the Johnson Space Center in Houston, Texas.

These three factors made it possible for major contractors to work together effectively, because interfaces were defined rigorously, with great depth of detail. The issuance of interface control documents compelled early resolution of any conflicts.

How well did it all work in practice? According to George M. Low, now president of Rensselaer Polytechnic Institute in Troy, N.Y., and director of the manned Spacecraft Center at Houston's Johnson Space Center during the Apollo program, "Perhaps the most important lesson of Apollo was deliberate design to minimize complex interfaces, thus making the systems-engineering task manageable."

The enterprise also holds lessons for conducting the business of technology. One aerospace industry veteran, James E. Ashton, vice president and general manager of the Tulsa division of the Rockwell International Corp., said, "The success of Apollo proved that even very large, terribly complicated goals can be achieved by breaking problems down into smaller problems and smaller goals. These then can be fenced in and treated as entities both from a business point of view, with contracts, and from a technical point of view, with interface-control drawings. Later the success of the shuttle orbiter proved the value of that concept to the design and apportionment of the system among many contractors."

Though the practice of engineering was driven to new heights by the space program, there were other effects that now profoundly influence many aspects of life. Robert Seamans, once NASA's deputy administrator and general manager and now the Massachusetts Institute of Technology's dean of engineering and head of its Energy Laboratory, credited James E. Webb, NASA's first administrator, for vision that went beyond his role in office. He foresaw the scientific aspects of being in space, the projected spinoffs into aeronautics, and the role that university research programs could play in ensuring success.

Mr. Webb so impressed President John F. Kennedy with this vision that he was able to get an unusual item in his budget: NASA support for several thousand doctoral candidates per year. He also got approval for a NASA grants program to put laboratories on campuses. This went beyond the need for specialized Government facilities, for Mr. Webb stated that he wanted research done "not only where the best minds would be involved, but also where the work would be tied closely to the educational process."

The NASA administrator asked the presidents of the 15 to 20 universities that received those grants to sign a letter saying they would make their best effort to set up a multidisciplinary activity on campus to look at all the ramifications of the space program. Not all the university programs germinated by NASA's grants program under Mr. Webb still have such clear-cut labels as MIT's Science, Technology, and Society Program, but multidisciplinary research flourishes.

Mr. Webb was also instrumental in the positioning of new Government laboratories. He insisted that they be established on or adjacent to campuses rather than in outlying industrial parks, so there would be "a fluxing of ideas with universities." Consequently a NASA Electronics Research Center was put right in the middle of Cambridge, Mass., within a stone's throw of four large universities, rather than in the high-technology–industry concentration along Route 128.

In a similar vein the unique concentration of scientists and engineers at space centers and test sites around the United States may have polarized the subsequent location of high-technology industry there. Inevitably such a concentration of talent upgraded education in surrounding communities, which in turn contributed new local talent to attract high-technology industries. ◆

COMPUTERS: LEARNING FROM DINOSAURS

Of all the electronic legacies attributed to space-age advances, computers share popular credit with communications satellites. However, history shows that fallout from space-flight efforts has led only indirectly to the $40 computers in discount stores today.

Pushing the state of the art was not what the National Aeronautics and Space Administration set out to do. Despite the ambitious, elegant language of the National Aeronautics and Space Act, NASA's early years were affected by the overtones of a race for the international political prestige to be garnered from manned space flight. When that objective was escalated to the unprecedented technological achievement of putting the first men on the moon and safely returning them to earth, the space agency sought proven—or at least provable—technology.

Despite ongoing advances in the science of computing, NASA elected to build and fly what might become computer dinosaurs. This convervatism turned out to be appropriate in terms of mission successes and the safety of the astronauts. But even the creation of dinosaurs affected the future of computing.

Valuable lessons were learned in designing computers to fit into small, tight spaces. Advances in software development and debugging emerged, including a new method for program interrupts that today is called memory-cycle stealing. And, most critical for the space effort, designers and vendors learned new approaches to component reliability.

As the Apollo moon shot effort moved into high gear in 1961, not all the technical problems had been solved. Eldon C. Hall of the Massachusetts Institute of Technology's Instrumentation Laboratory in Cambridge, who led the development of the Apollo guidance computer, reminisced that if his design team had known then what they learned later, they probably would have concluded they could not build the computer that was needed with the technology of the early 1960s.

As the manned space-flight program took shape, there was little question that the computer power then available could provide real-time guidance and control for the spacecraft. The tech-

Evan Herbert Contributing Editor

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nology had been proved in most of the ground-based computers in existence in 1960. These were parallel general-purpose computers that had been designed in the late 1950s. The trouble was that few such machines, though they had the power for the contemplated moon missions, had been designed for the aerospace environment. Those that had been squeezed down to meet the size, weight, and power-supply parameters also embodied substantial compromises in computational performance.

The moon mission was extremely complex. It required enormous computing power that would be reliable and self-sufficient, for the spacecraft would be in a communications "shadow" during part of its translunar flight. Functioning as a general-purpose computer, the spacecraft's computer system would have to solve the guidance and navigation equations for the mission. As a control computer, it would handle such major functions as aligning the inertial measurement unit, processing radar data, managing the astronauts' displays and controls, and generating commands to control the engines.

On top of that, two computers were needed for the Apollo missions—one in a command module and the other in a lunar excursion module. This particular configuration of the Apollo spacecraft was the culmination of a technical controversy over whether the guidance problem for lunar orbit rendezvous could be solved at all.

Fortunately, rendezvous technology had been advanced considerably by military projects aimed at satellite interception. If it was possible to maneuver an unmanned inspection vehicle alongside an orbiting satellite, why not guide and dock together two manned spacecraft with essentially the same techniques? The guru of guidance and navigation, Charles Stark Draper of MIT's Instrumentation Laboratory, was so certain of the technological feasibility that he volunteered to go along on the first mission to run the computer.

The MIT laboratory had been working on basic guidance and navigation problems since the late 1950s under an Air Force study contract. From this work, on flight-path analysis for a spacecraft to photograph Mars and then return, emerged a unique design for a guidance and navigation computer. Though the Mars computer was never built, some of its features would be carried over into the Apollo guidance computer, as would the packaging techniques for a guidance computer developed by the MIT Instrumentation Laboratory for the Navy's Polaris submarine-launched ballistic missile.

By August 1961, MIT had received the NASA contract to design the Apollo guidance computer. The engineers of the Instrumentation Laboratory, which today is the Charles Stark Draper Laboratory Inc., were faced immediately with the constraints of top-down design. Within a week of President John F. Kennedy's proclamation that the United States would put a man on the moon, a reasonably well-defined Apollo spacecraft had been unveiled. The computer engineers were told they had a small hole in the equipment bay to fill with a functional system. It was to guide and control the entire flight to the moon and back, including rendezvous and linkup with the lunar excursion module. The area in the command module available for this task consisted of 1 cubic foot for the computer and some panel space for two display and keyboard devices for the astronauts [see photo].

To pack the system into that space would require high-density information storage. A suitable read-only fixed memory had been developed for the Mars computer. It was a core-rope memory, a transformer type that depends for its storage on weaving patterns into sensing wires at the time of manufacture. A stored bit is a 1 wherever a sense wire threads a core, and a bit is a 0 wherever a sense wire is not threaded through a core.

Though the content of a core-rope memory becomes unalterable, the medium is highly reliable, offering a density of 1500 bits per cubic inch, including all driving and sensing electronics, as well as interconnections and packaging hardware. At the time this was a 5-to-1 improvement over currently available coincident memory. There was room for six 6-kilobyte rope modules in the computer, offering 36 000 16-bit words of fixed storage, which would require advanced delivery of thoroughly debugged software so the information could be wired in.

The additional lead time imposed by hardwiring may have been responsible for the extraordinarily error-free mission performance of Apollo computers. It bought more time for checking and debugging after a memory had been manufactured for a particular mission.

Still, there was room for inadvertent error, as former Astronaut Jim Lovell recalls. He was the navigator on Apollo 8, the first flight to the moon to test the navigation capability of the system. On the return trip he accidentally punched up the wrong program, and the guidance system began to present information as if the spacecraft were still sitting on the launch pad at Cape Kennedy. It also lost all reference data to determine the attitude of Apollo 8 with relation to the celestial sphere. Mr. Lovell recovered by peering out the portholes for recognizable stars and manually updating the guidance system via the 2048-word coincident core-erasable memory to get the inertial attitude platform back into alignment.

Architecture and hardware contributions

Though the Mars computer design had provided some precedents, a significant contribution to aerospace computing archi-

tecture was a program-interrupt method of accommodating real-time inputs and outputs. Large-scale computers had begun to use it prior to the Mars project. The interrupt method was incorporated into the Apollo guidance computer for single access to memory to accomplish incrementing or shifting. This process, now known as memory-cycle stealing, has been widely used to link computers to peripheral devices.

One of the architects of the Apollo design recalls his reason for selecting core-transistor logic: it already was a proven technology, and the transistors would be turned on only when used, thus requiring less power. This translated into less weight and space.

Meanwhile the hardware technology available to aerospace computer designers was developing rapidly. Because the Air Force had been pushing the development of integrated circuits by the semiconductor industry since the late 1950s, it seemed to the project manager, Mr. Hall, that the burgeoning computer might be squeezed into state-of-the-art circuitry. However, he was concerned about reliability. An estimate of component failure rates and component counts showed that the resulting computer failure rate was too high to ensure a successful mission. Reliability could be increased by conventional techniques of redundancy, but the design would then exceed the requirements for power, size, and weight. The alternative was to seek computer reliability through more reliable components and manufacturing procedures.

The number of component types and range of values was constrained to a select few, bringing complaints from the circuit engineers that their designs would be constricted. An iron-clad flight-processing specification oversaw the quality of component lots. Defective lots were subject to wholesale rejection, with no partial givebacks. Vendors complained bitterly, but what they were forced to do in order to achieve reliability was underwritten by the ample budgets of the Apollo program. Later they accepted the reliability lessons learned from required internal visual inspection before crates were packaged or systems were sealed and all parts were burned in. As a result, the Apollo computer was a pioneer in the flight into space of nonredundant integrated circuits.

A delayed impact of software

Because the computer programs were entered into the core-rope memories by the actual manufacturing process, software had to be developed and debugged well in advance of each flight. By the time Apollo 11 lifted off the pad, the software team, led by Margaret Hamilton, had analyzed software management and development techniques and the software itself. The team found that 73 percent of the problems were interface-related— data and timing conflicts within the software. Moreover, 60 percent of the problems found in a given program release turned up in other releases already approved. Though they expected to solve the software reliability problem by eliminating errors, it turned out that a major improvement came from defining a system in such a way that interface ambiguities could no longer exist among the software modules.

The empirical study of the Apollo software enabled the categorizing of axioms and definitions for scanning whole classes of errors—program statements that were inconsistent, redundant, or logically incomplete. This effort evolved into a theory of higher-order software that was applied to system definition processes to get rid of interface errors. Ms. Hamilton set out to prove the theory, for she felt that it could be the basis for automating not only the verification process, but also the software-development process. She is now president of a company called Higher Order Software, with fully automatic software products that generate bug-free systems.

Impacts of other computer activities

Though the manned spacecraft program made the greatest use of the new capability of advanced computers, they were also used extensively for simulation, preflight checkout, launch control, in-flight monitoring, and data reduction from telemetry. James E. Tomayko of Wichita State University in Kansas said NASA enjoyed its greatest success in computer simulations. These allowed experiments with equipment and plans, as well as extensive crew training. Mr. Tomayko saw that the perfect flight record of the Saturn booster proved the efficiency of modeling that aided the development of the launch vehicle. He credits NASA's continued refinement and use of simulations to the fact that the space shuttle was man-rated on its very first flight.

The 4Pi series hardware and software used today in space shuttles was influenced by the special-purpose flight computer that IBM Corp. built for NASA's Gemini program in the 1960s. It made the first use of on-board auxiliary storage—a magnetic tape unit with identical programs on three tracks, read through voter circuits before the data entered the computer. It was another approach to reliability—through redundancy. Multiple redundancy and fault-tolerant equipment flies on today's shuttles in systems configured of five IBM 4P8/AP-101 computers and two mass-memory units. ◆

TELECOMMUNICATIONS: CLARKE'S LEGACY

While this year marks the twenty-fifth year of the National Aeronautics and Space Administration, another anniversary was marked this summer: the twentieth anniversary of the launching of Syncom II on July 26, 1963. Although there have been many significant events in the evolution of commercial satellite communications, none has had greater impact on this space technology than Syncom II, the world's first synchronous orbiting satellite. It demonstrated the technological feasibility of geostationary orbit communications, cemented the relationship between NASA and the commercial aerospace companies, and became the prototype satellite for the international Intelsat system, today the largest and most technically advanced communications satellite system in the world.

Three years before Syncom II went into orbit, NASA had inaugurated the era of satellite communications when it launched the balloon Echo I. Then Telstar I, built at Bell Laboratories and launched by NASA in 1962, demonstrated transoceanic communications via satellite [see "Space-technology milestones," p. 57]. But Echo was merely a passive reflector, and Telstar's orbit was too low, limiting its broadcasts to too little of the earth's surface to be economically useful. Also, both had to be tracked by ground stations, since their orbital period was not the same as that of the earth's rotation—a complex task even today.

The properties of geostationary orbit had been described as early as 1929 by the Austrian engineer Hermann Noordung, and a communications relay in this orbit had been predicted in 1945 by Arthur C. Clarke, a science-fiction writer. Simply put, a

Mark A. Fischetti Associate Editor

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New ACTS in communications

By the early 1970s, with the Comsat Corp. set up and the intelsat program a success, the United States satellite communications industry was flying high. So fast was the progress, in fact, that in 1972 Congress determined there was no longer a need for Federal investment in research and development. Funds authorized for this purpose by the National Aeronautics and Space Administration were dropped.

But by 1978 it had become apparent that this was a shortsighted decision. Satellites were crowding available North American orbital slots, and broadcasts of the same frequency in both the C (4 to 12 gigahertz) and Ku (12 to 18 GHz) bands were nearly overlapping. Causing even more alarm was the fact that both Japan and Europe were capturing larger shares of the commercial communications market.

In the 1982 budget Congress reappropriated funds to bring NASA back into the research and development picture. The Advanced Communications Technology Satellite (ACTS) program resulted. It should enable NASA to launch by 1988 a communications satellite with 100 times the capacity of present satellites in orbit. If successful, the demonstration model will establish a communications technology base in the U.S. sufficient to handle demand for three decades.

The satellite will make use of three new features. First, it will be capable of receiving signals at 30 GHz and transmitting them at 20 GHz (most satellites today receive and transmit at 6 and 4 GHz, or 14 and 12 GHz, respectively. The new capability will enable the satellite to handle a wider spectrum of signals. This will require improved radio-frequency components and antennas. Japan now has in orbit a 30/20-GHz satellite, the CS2A, and several European interests are working on similar systems.

Second, in addition to 18 fixed antennas, the satellite will be equipped with six multiple-spot beams, so it can transmit signals to highly localized areas on the ground. Different signals of the same frequency will be broadcast to different areas within the satellite's range, thus expanding the effective capacity of the satellite. On-board switching systems to control this operation are being developed. The television industry uses very high-frequency broadcasting in the same way. On Channel 2, for example, different programs are broadcast in New England, the Midwest, and California, because the broadcast coverage is localized.

Finally, the capability to process and store signals on board the new satellite will increase its capacity. This feature will be used when real-time communication is not necessary, such as when one computer sends a message to another. More importantly, the satellite will act as a switchboard in the sky for major telephone trunklines that are always overloaded, like that between Chicago and New York, directing traffic as it is received to the appropriate down link. The development of such a switchboard that can survive a launching and operate remotely in orbit is the challenge. —*M.A.F.*

satellite placed in geostationary orbit could make 24-hour telecommunications possible across a large portion of the earth's surface, and several coordinated satellites could provide worldwide broadcast coverage. What's more, ground stations would not have to track a satellite's movement; it remained in the same spot with respect to the earth's surface, effectively tethered there by a tower 22 300 miles high.

However, the prospect of achieving this goal in 1959 was bleak, recalled Harold A. Rosen, vice president of engineering at the Hughes Aircraft Co. in El Segundo, Calif., who began that year to develop a lightweight, geostationary communications satellite at Hughes. Launching vehicles at that time would not have been able to lift satellites then being considered for this purpose, and even if launchable, Dr. Rosen said, those designs called for hardware too complex to have a reasonable life expectancy.

"It then occurred to me," he remembered, "that the satellite's size and complexity could be greatly reduced if it were set spinning in its orbit." Spinning would simplify the satellite's control system and would permit a toroidal antenna beam to keep in continual contact with the earth. It would also simplify the orbit-control system. The simpler configuration resulted not only in better reliability, but it also lowered the satellite's weight. Additional weight was to be lost by use of a solid-state receiver.

Three advances made by three development team members at Hughes—Donald Williams, Thomas Hudspeth, and John Mendel—finally led to a simple, lightweight system, Dr. Rosen noted. The first advance was the method of attitude control; it relied on spin-phased impulses, which exploited the dynamics of the spinning satellite body, thereby reducing the number of attitude-control thrusters needed. The second was a series of receiver and antenna elements that were "years ahead of their time," Dr. Rosen said. And the third was a new rugged but lightweight traveling-wave-tube transmitter.

In 1960, the team began looking for a sponsor to launch its satellite. Its initial proposal was turned down by all U.S. and European government agencies and by every communications company approached. Critics doubted that the satellite would remain precisely in its orbit and that its antennas would stay pointed in the same direction. They also questioned the quality of voice communications via a geostationary satellite, because of the propagation time delay caused by the satellite's high orbit. Electromagnetic signals take approximately one quarter of a second to travel the 22 300 miles up to a geostationary satellite, be repeated, and travel back down to a ground station. For two-way communication, this means a half-second round-trip delay.

With that long a delay, any echo on the circuit muddled voice communications. But the team showed that echo suppressors could be used to reduce the interference. The suppressor, simply a voice-operated switch, worked well if only one person spoke at a time. Simultaneous conversation still presented problems, but this was not deemed a major complication by communications engineers. For television communications, a continuous broadcast, the delay would simply be adjusted for at the start of a broadcast.

Finally, in late 1961, Dr. Rosen's team persuaded NASA, in cooperation with the Department of Defense, to test its concept. The effort became known as the Syncom program (for synchronous communications).

But even as they wrestled with critics, the Rosen team realized that they needed a way to boost Syncom high enough to reach geosynchronous orbit, as well as a way to synchronize it once it was up there, so it would stay in place. The trick was to propel the satellite in three stages. Earlier low-orbit satellites, like Telstar, were simply inserted into desired orbits directly by the launching vehicles when the booster stage burned out. Syncom required an additional stage—an apogee kick motor, a small, solid-propellant rocket built into the satellite [see photo, p. 62].

The plan called for the launching vehicle to insert the satellite into an elliptical orbit with an apogee of 22 300 miles—the radius of a geosynchronous orbit. At that point the kick motor would fire to propel the satellite at 4000 mph in the direction of orbit, fast enough to lock it into a geostationary orbit.

"The idea sounds so simple," noted C. Lewis Cuccia, who was involved in satellite communications at Ford Aerospace Corp. at the time, "but someone had to be the first to do it."

Ironically it was the kick-motor phase that caused Syncom's

first failure. The first satellite was launched in February 1963, but it exploded when boosted into final orbit.

That July, however, Syncom II was successfully launched, demonstrating communications via a synchronous satellite (Dr. Rosen pointed out that it was not strictly a geostationary orbit, because the orbit was inclined relative to the equator).

It was then that the Comsat Corp., incorporated by the U.S. government the day Syncom I was launched, realized that if it hurried it could start business with a bang. The privately funded, quasi-governmental corporation had been set up to exploit satellite communications.

"Comsat said to itself, 'Hey, if we could get a television link to bring live coverage of the Olympics in Japan, we'd have a good kicker to start business,'" Dr. Cuccia remembered. Comsat approached him, he said, and told him he had three months to develop a receiver for this link. What resulted was the first telecommunications maser, a low-noise amplifier in which a signal is boosted by changes in the energy levels of atoms in a crystal. The amplifier was mounted on a relay station at Point Mugu in southern California, giving the station the added sensitivity it needed to relay signals from Japan. The live transmission of the opening ceremonies was carried by Syncom III, the first true geostationary satellite launched a few months earlier.

Noting the success of Syncom, Comsat contracted with Hughes to develop a similar satellite that was to become the first link in a global communications system operated by the International Telecommunications Satellite Consortium (now the International Telecommunications Satellite Organization, better known as Intelsat). The launching on April 6, 1965, of Earlybird, now referred to as Intelsat I, ushered in a new era of international satellite commercial communications in telephone, telegraph, and television. In one stroke, Intelsat I doubled the transmission capacity of all existing transatlantic cables. ◆

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REMOTE SENSING: THE BEST VIEW IN TOWN

Remote-sensing satellites orbiting some 900 kilometers above the earth are still a source of wonderment to many space scientists and engineers. A sensor satellite "can see the whole world," said Dudley McConnell, an assistant associate administrator with the National Aeronautics and Space Administration. Both land masses and oceans can be viewed in the visible, infrared, and microwave portions of the spectrum. Weather-radar sensing, as exemplified by the Nimbus series, is thought of as being the highlight of the 1960s, the Landsat series that of the 1970s, and imaging radar that of the 1980s. Nonetheless, land-resources sensing, although only a small portion of all remote-sensing activities, is a powerful example of this technology.

Today, only 11 years after NASA's successful launching of the first earth-resources technology satellite, ERTS 1 (later renamed Landsat 1), data from these satellites are helping to forecast agricultural crop trends, explore for oil and minerals, monitor water resources, map vegetation and forests, plan land use, and produce geographic maps.

NASA has launched four earth-resources satellites so far--Landsats 1 through 4. The first two have finished their missions successfully, although they are still orbiting the earth. Landsat 3 is transmitting only about 60 percent of each earth image it picks up, and, as of last June, Landsat 4 was disabled because a cable carrying power from its solar array had failed, along with an X-band transmitter.

NASA officials were hoping, however, to receive data later this year through a backup transmitter in the Ku band. This transmitter is aimed at NASA's new tracking and data-relay satellite system, which was maneuvered into geostationary orbit last June after it had failed to achieve the proper orbit when launched from the U.S. Space Shuttle Columbia on April 4. NASA engineers are considering retrieving and repairing the ailing satellite during an upcoming space mission. Another alternative under consideration is the launch of a backup satellite for Landsat D next year.

According to Dr. McConnell, three technological developments have made remote sensing as we know it today possible:

1. The capability to mechanically stabilize satellites in three axes simultaneously.
2. The capability to scan a scene optically hundreds of kilometers away and to obtain enough meaningful detail about it.
3. The capability to derive useful information from large amounts of data.

Modest beginning in the mid-1960s

The debut of land remote sensing was modest enough. In the mid-1960s the Willow Run Laboratories of the University of Michigan, known today as the Environmental Research Institute of Michigan, introduced an airborne multispectral scanner. The development of techniques for extracting useful information from multispectral data and the study of practical uses of the data received a great boost when Landsat 1 was launched, according to Pitt G. Thome, a remote-sensing specialist who recently retired from NASA's Office of Space and Science Applications. Landsat 1, he noted, made large amounts of data available on a global and continuous basis.

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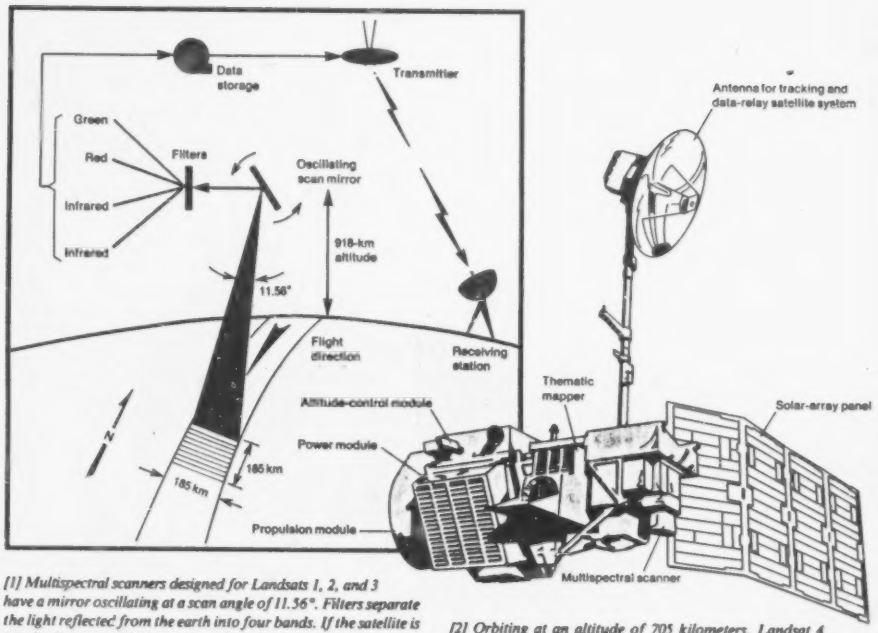
composed of 6000 charge-coupled devices 13 micrometers apart are to be placed in each sensor's focal plane—one array assembly per spectral band—to pick up and respond to light reflected from the earth. Each line of the image is to be electronically scanned by a line of detectors within the array. Successive lines of the image are to be produced by the satellite's own movement in orbit.

NASA is currently supporting the development of similar technology under its multispectral linear-array program. The program includes the development of advanced multispectral detectors for visible light and shortwave infrared radiation, optics, on-board signal-processing technology, and sensor-design studies. Imaging spectrometers also are to be developed for testing during space shuttle flights beginning in 1987. More advanced sensors for shuttle missions lasting one month or so, as well as for space platforms for the 1990s, are also under study.

Data-processing bottleneck reported by NASA

There is at present a large operations bottleneck at Goddard Space Flight Center in Greenbelt, Md., where Landsat data are processed. Luis Gonzales, the Landsat 4 project manager there, noted that it takes a whole day to process just one thematic-mapper scene that includes seven pictures of a 185-by-185-km area, one picture for each of the seven spectral bands. Even with an expected increase in capability to 12 scenes per day, the processing rate would still be too slow; many images will have to be stored on tape until they can be processed. NASA is sponsoring an investigation into such areas as artificial intelligence, expert systems, and new textual-analysis techniques, hoping to find ways to minimize the delay. ◆



[1] Multispectral scanners designed for Landsats 1, 2, and 3 have a mirror oscillating at a scan angle of 11.56°. Filters separate the light reflected from the earth into four bands. If the satellite is too far from a receiving station, then the data are recorded and stored on board and are transmitted at a later date. (Figure adapted from a NASA drawing in Landsat Data Users Handbook.*)*

[2] Orbiting at an altitude of 705 kilometers, Landsat 4 carries a multispectral scanner and a thematic mapper. Each sensor scans a strip, or swath, of the earth 185 kilometers wide, with successive swaths overlapping to ensure complete coverage. Each swath is scanned every 16 days.

Today about a dozen nations have facilities that can receive and process data directly from Landsat 4. More than 100 nations use data from this satellite to help manage their resources. At the heart of this widespread use is a U.S. policy "to make Landsat data readily available on a nondiscriminatory basis throughout the world," Mr. Thome observed.

Landsats 1 and 2 are essentially identical: both include multispectral scanners [Fig. 1] and three high-resolution return-beam vidicon tubes, or television cameras, that provide black and white imagery. The spatial resolution of both types of sensors is 80 by 80 meters. Landsat 3 has a multispectral scanner and two identical broadband television cameras that produce black and white images at a spatial resolution of 40 by 40 meters.

The multispectral scanners on Landsats 1, 2, and 3 were designed to respond to light reflected from the earth in four spectral bands, covering green to infrared (0.5 to 1.1 micrometers). The multispectral scanner on Landsat 3 has an additional set of detectors for a thermal infrared band of 10.4 to 12.6 micrometers, although this band failed shortly after launching.

Meanwhile extensive analysis of data from Landsats 1 through 3 has shown that the data could be much more useful if the scanners could resolve scene elements one half to one third the size of 80-by-80-meter resolution elements, the smallest details these scanners can identify today. Furthermore, research with airborne scanners has shown that an additional band in the shortwave infrared region—1 to 2.5 micrometers—would be desirable to study vegetation and geological formations.

Additional research and development has led to a more powerful sensor known as the thematic mapper. Orbited on Landsat 4, along with multispectral scanners identical to those on the first two Landsat satellites [Fig. 2], the thematic mapper covers seven different bands: six of reflected sunlight in the 0.45-to-2.35-micrometer range and an infrared thermal band of 10.4 to 12.5 micrometers. Scene or picture elements (pixels) of 30 by 30 meters can be identified in the reflected light bands, whereas a 120-by-120-meter pixel is the smallest element detectable in the thermal band.

Spaceborne sensors with the highest spatial resolution yet for nonmilitary use are being prepared in Europe under a joint program conducted by France, Sweden, and Belgium. The sensors—two identical high-resolution instruments for visible light—are included in the Systeme Probatoire d'Observation de la Terre (SPOT) satellite to be launched in January 1985 as part of France's national space program. In orbit at an altitude of 832 kilometers, the sensors would have a ground resolution of 10 by 10 meters in a panchromatic band at 0.51 to 0.73 micrometers, and the resolution would be 20 by 20 meters if the sensors were used as multispectral devices in three color bands.

Because fine ground resolution is highly important, mechanical or "spot" scanning, such as in the multispectral scanners and thematic mapper, has been discarded by the European program in favor of an electronic method. Linear arrays

RELIABLE POWER: APPROACHING PERFECTION

The designers of Skylab's solar-cell arrays had good reason to worry after the spacecraft's launching on May 14, 1973. Part of the array assembly, they learned, had ripped off during the launching because of a mechanical problem. The power supply for the spacecraft was crippled. With just over 5 instead of 10.5 kilowatts available at any given time, Skylab's crew still completed the mission successfully. Once again photovoltaic arrays for spacecraft proved to be highly reliable.

Since the beginning of the space era no mission has ever failed due to solar-array failure, said Henry W. Brandhorst, who heads the space photovoltaic branch at the National Aeronautics and Space Administration's Lewis Research Center in Cleveland, Ohio.

What makes solar-cell arrays so reliable is high redundancy, stemming from the series and parallel connections of individual cells, according to Dr. Brandhorst. Because Skylab's photovoltaic system was the largest ever flown, the cell interconnections there were tricky. The system comprised two separate power supplies—one of a little over 10 kW for the Apollo telescope mount and the other a 10.5-kW system (this was damaged on launching in 1973) for use by the crew [Fig. 1]. The telescope's supply had more than 164 000 individual silicon solar cells, about three quarters of which were 2 by 2 centimeters and the rest 2 by 6 cm. The other supply had nearly 150 000 silicon cells, each 2 by 2 cm. The total area of each of the supplies was about 144 square meters.

Though typical spaceborne solar-cell arrays, such as those used in communications satellites, range 1 to 3 kW, Skylab's 20-kW system was a forerunner of things to come. In the next decade NASA proposes to put into orbit several sizable spacecraft, and perhaps a space station, which are expected to require large amounts of power for running experiments, handling data, controlling thermal conditions, and stabilizing the spacecraft.

NASA has also proposed that a special service platform, also identified as a power module, provide power and other services to other spacecraft. Services would be performed during docking in space. Variations on this idea are under study also at the European Space Agency's research and technology center in Noordwijk, the Netherlands, and at France's Centre National d'Etudes Spatiales in Toulouse. All three approaches call for anywhere from 20 to 30 kW to be available on the power module.

According to Klaus Bogus, head of the solar generators sections at the Noordwijk center, the solar arrays for such a future module would be light, highly modular, and easily deployable and retractable. They would operate at a voltage several times higher than that of today's solar arrays, he said.

Cheaper, thinner cells with higher efficiencies and larger areas are also being sought, according to Dr. Bogus. Work is under way in several countries on system, subassembly, component development, and such interconnection techniques as welding.

In the United States, NASA's George C. Marshall Space Flight Center in Huntsville, Ala., is preparing to test next year an

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array of thin silicon cells mounted on a two-layer blanket of Kapton, a flexible plastic material. The space agency sees this array as a radical departure from the solar array on Skylab. Supported by an aluminum honeycomb structure, the Skylab array offered 7 watts of power for each kilogram of array, said Dr. Brandhorst, whereas the goal for the new array is 66 W/kg. To minimize the costs of next year's test, only two of the array's 84 panels will actually have solar cells. When fully wired, such an array is expected to deliver 12.5 kW.

Though the primary purpose of the flight is to determine the deployment dynamics of this large, flexible structure, another objective is to obtain the operational characteristics of three types of solar cells. One type is 2-by-4-cm and another 5.9 cm on a side. Both are 300 micrometers thick and are capable of 13-percent efficiency. The third type will be 2 by 2 cm and only about one fifth as thick as the two other types. Its efficiency is projected to be 10.5 percent.

The European Space Agency is planning to launch in 1986 a satellite with a 4-kW solar-cell array on a flexible Kapton substrate, having successfully operated the experimental Hermes satellite with a similar, though smaller (1.3-kW), array from January 1976 to December 1979.

Gallium arsenide cells under development

Meanwhile NASA, the U.S. Air Force, and others have begun to develop spaceborne gallium arsenide solar cells as a major competitor to silicon. Research has already demonstrated that gallium arsenide cells are more efficient than silicon cells, are substantially lighter per given output power, can maintain acceptable efficiencies at much higher temperatures, and are expected to have twice the useful life of silicon cells because they are less susceptible to radiation damage.

To test gallium arsenide cell performance in space, the U.S. Air Force placed such a solar-cell array on a U.S. Navy satellite launched in February. Orbiting the earth at about 960 km, the array has 300 2-by-2-cm cells with efficiencies of 16 to 18 percent and total power of up to 25 W. The experiment is expected to last about two years.

NASA's Dr. Brandhorst indicated that the gallium arsenide processing technologies employed for photovoltaics are also useful in microelectronics high-speed circuitry. For example, researchers at the Lewis Research Center recently came up with a new technique for heavy doping of semiconductors in the production of a cascade cell structure. The technique is expected to lead to advanced microcircuits, Dr. Brandhorst said. ◆

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THE SPACE-AGE MATERIALS CHALLENGE

When three astronauts for the Apollo 1 mission were killed in a flash fire aboard the spacecraft at Cape Kennedy, Fla., on Jan. 27, 1967, the threat of fire, a constant concern to one segment of space-materials scientists, was vividly realized. After the accident, the National Aeronautics and Space Administration moved to eliminate every possible fire hazard on spacecraft. At the same time, the Federal Aviation Administration began to examine comparable fire threats on airliners to see if they, too, could be avoided. NASA succeeded in its efforts, but few of the FAA's good intentions have been put into action.

Mark A. Fischetti Associate Editor

The fire broke out on the launching pad at 6:31 p.m. while the three astronauts—Virgil I. Grissom, Edward H. White, and Roger B. Chaffee—were taking part in a full-scale simulation of a scheduled Feb. 21 launching that was to take them to the moon. Emergency crews tried to reach the astronauts but were blocked by the dense smoke that rolled out of the cockpit.

Officials never were certain of the precise cause of the fire, but they concluded that an electrical short circuit had ignited materials in the pure oxygen atmosphere inside Apollo 1. NASA had known that the simplified atmosphere ran a risk of fire; in pure oxygen almost everything burns. The equipment needed for a two-gas system of oxygen and nitrogen, however, was deemed too heavy to fly.

"The assumption before that accident," recalled David H. Greenshields, assistant of NASA's structures division at the Johnson Space Center outside Houston, "was that although pure oxygen and flammable materials were on board, all the potential fire-ignition sources had been eliminated. The fire showed NASA could not count on that."

Spacecraft atmospheres since then have been gradually altered to resemble air and are today nominally 78 percent nitrogen and 21 percent oxygen. But NASA thinking has changed also. "Now," Mr. Greenshields said, "the assumption is that there is an ignition source."As a result, flammable electronics are contained in nonflammable containers, and construction materials are chosen so that "nothing will burn, even in pure oxygen."

With an ample selection of fireproof materials for spacecraft cabins, the problem is which to pick and test, according to R.L. Johnston, chief of the materials branch at the Johnson Space Center. After the Apollo fire, NASA turned to fire-retardant glass fibers for most of the seats and seat covers, flooring, wall panels, and packaging materials. With the advent of the reusable shuttle, however, a move to treated fabrics was made; glass material did not burn, but it wore through in only a few weeks of active use.

Poor wear and high cost, in fact, have prevented most commercial aircraft companies from using NASA's fire-retardant materials. One new material developed at the materials branch, however, may prove relatively rugged and inexpensive—a polyimide foam that can be used to construct airplane seats and floor and wall panels. It does not propagate a flame, and compared with currently used materials, it produces less dense smoke and fewer toxic fumes when it smolders. These are all important qualities, since the primary claimer of lives in airline fires is the inhalation of smoke from materials ignited by fuel fires. Both United Air Lines and Pan American World Airways are now testing panels made of the polyimide. So far, Mr. Johnston reported, the panels are wearing well and do not discolor.

Fire and smoke propagation have been well studied at NASA, and researchers feel astronauts are now well protected. But aside from the tests just mentioned and some limited work with the Boeing Aircraft Co. and the Federal Aviation Administration, the technology transfer to commercial airlines has not been great. The fire last June 2 aboard an Air Canada DC-9, in which 23 people were killed as the jetliner landed in Cincinnati, has revived longtime disputes over fire safety in airlines. Improved materials would not have prevented the fire, but they might have slowed its spread and more passengers might have gotten out alive. Though many air-safety officials agree that considerable progress has been made in fire-retardant materials research, they nevertheless contend that FAA regulations and industry standards lag far behind the state of the art. ◆

THE ART AND SCIENCE OF ERGONOMICS

Two questions that have dogged the designers of spacecraft crew stations concern how much information can be crammed onto a display before the display becomes confusing to astronauts, and how many controls they can effectively use. In the early days of space exploration, the designers of spacecraft got their answers from the builders of airliners. Today the airline engineers borrow from spacecraft designers.

In 1962, when John H. Glenn Jr. was lifted into orbit on the Friendship 7, how to best design displays and controls, and how to implement the instrumentation behind them, were decisions driven by technology already used in airplanes. But due to demand for more unique and specialized spacecraft in the 1960s and 1970s, epitomized by the space shuttle, crew-station technology has become the model for airplane cockpits.

Traveling at 17 500 miles per hour, astronaut Glenn saw four sunrises in five hours. He also saw a relatively simple instrument panel, which allowed complete control by the pilot but which reflected the minimal demands of the mission [Fig. 1]. In fact, the Gemini craft could have been remotely controlled from the ground. Astronaut Glenn, in his cramped quarters, relied strictly on toggle switches and needle gauges. Attitude information, for example [far left in photo], was displayed on three meters, one with a horizontal needle moving in the vertical plane and two with vertical needles moving in the horizontal plane. The circuitry behind the instrument panel depended on fuses, and there was no computing capability on board.

The same kind of toggle switches and needle gauges abounded in cockpits in airliners of the day, of which the Boeing 707 was typical [Fig. 2]. Desired features not included on Friendship 7 were color displays to help the crew differentiate between important readouts. But a three-needle system to show pitch, roll, and yaw was used, as on Friendship 7.

At first glance, the Boeing 767 [Fig. 3], introduced on commercial airlines this year, does not appear much different from its 20-year-old counterpart. But much has changed, behind the flight deck as well as on the panels. Electromagnetic equipment has been replaced by faster digital electronics, improving instrument performance. Denser circuitry has increased the capacity of on-board diagnostic equipment. Also, an inertial reference system using laser gyroscopes has been rigidly fixed to the jetliner, replacing the gimballed gyros set spinning on earlier planes. Color cathode-ray-tube displays, first flown aboard Skylab, and digital readouts have replaced most of the needle gauges.

The three-needle attitude system, for example, has been replaced in the 767 by a CRT display centered in front of each flight-control column. It shows attitude information and the orientation of a graphics symbol of the actual plane being flown on an artificial horizon. This idea is repeated in the radar system (the second CRT in front of the column, below the attitude indicator). It provides an integrated multicolored map of the plane's position relative to waypoints and instrument-landing-system beams. A colored radar display can be superimposed on the map to show weather conditions. The airplane's position with respect to the ground, and any deviation from a preplanned route can also be displayed, lessening interpretation demands on the crew. Overall, there are fewer controls and meters than in the 707, even though the 767 is a larger and more complex craft. This has simplified the crew's tasks enough to permit optimal operation by only two people, rather than three in the 707.

By the same token, the space shuttle is also more complex than Apollo crafts were, but only a commander and pilot are needed to carry out all flight functions, compared with Apollo's three-man team. Many of the instrumentation advances in the 767 were based on those already in the shuttle, which was built by Rockwell International [Fig. 4]. Moreover, the shuttle, preceding the 767 by two years, goes the airliner one better, performing like a spacecraft in flight and an aircraft during landing. Color CRTs show the shuttle's attitude and its position after reentry from space with respect to landing beacons and other aircraft. Computer data and text are also displayed. The pushbutton flight deck, the digital electronics and microprocessors behind it, and the greater visibility and room to move about are all quite a change from the cramped, toggle-switch-controlled, fuse-dependent Friendship 7. ◆

Mark A. Fischetti
Associate Editor

SUPERPROJECT MANAGEMENT

Not since the Manhattan Project atomic bomb effort of World War II had there been such a massive mobilization of technical talent in the United States as that started in the late 1950s to conquer space. Backstage it was replete with the rivalry of competitive technological approaches to objectives that initially were defined in only the broadest of terms.

Suddenly systems thinking was forced to gel by the imposition of a political timetable. Another Soviet space triumph on April 12, 1961—a man in space only three and a half years after Sputnik had become the first object into orbit—sparked concern that the USSR planned an even greater space spectacular for its 50th anniversary. U.S. officials speculated that the Russians would be shooting for the moon and so they set out to get there first. The U.S. goal: men on the moon by 1967 or earlier.

In astonishingly short order, often after only months, earth-based and space systems had to be born all at once, rather than be allowed to evolve. To meet the timetables, systems were carved into an enormous number of technical tasks and parceled out as projects. The output of these projects, both hardware and software, would have to mesh with exquisite precision with a timetable conceived even before technological feasibilities had been confirmed.

As the space race became increasingly political, it was put on a fast track and lubricated with money, a factor that enabled multiple technical approaches to be tried in parallel. The space agency opened in October 1958 as the National Advisory Committee for Aeronautics, an organization with a long record of technical excellence, though not much autonomy and political influence. The committee totaled 7900 people, most of them in its research laboratories and test centers, with 170 as a Washington headquarters staff.

Strengthening the aerospace infrastructure

By the time the Soviet Vostok 1 returned to earth in 1960, NASA had 17 000 people on its staff and was supporting industrial contracts involving 60 000 more people. By mid-1960, private industry was being groomed for a major role in the manned space-flight program. Most of the work would go to contractors.

But NASA was organized to exercise consistently strong control of every aspect of systems engineering. George M. Low, who headed the Manned Spacecraft Center, emphasized the tremendous strength centered in the relatively small project offices run by NASA's in-house work force. "The key to success," he said, "was a design that recognized the overall complexity of Apollo and separated the system into as many individual pieces as possible, with minimum interfaces."

The project offices at each of the Apollo Development Centers—the Johnson Space Center, the Marshall Space Flight Center, and the Kennedy Space Center—had systems engineering divisions that were integrated by a similar systems office in NASA headquarters. Contract systems-engineering teams from industry gave technical support to those divisions and separate checks and balances for the headquarters office.

When the Apollo program was put into high gear, a broad top-down design of the spacecraft had already been accomplished. Systems integration of the many functional subsystems was still a major challenge. The Apollo systems engineering approach deliberately anticipated the magnitude and nature of this challenge. For example, the decision to separate the spacecraft into command and service modules, and ultimately a lunar module, was to minimize complex interfaces. In fact, there were only about 100 wires between the spacecraft and the launch vehicle; the systems engineering between them was confined to the docking interface. Few determinations had been made of what actually would go into the boxes in a total system scheme that included launching, ground support through a global network of tracking and communications stations, space-vehicle guidance and navigation to the moon, lunar landing and exploration, and safe return to earth. Three contractors were assigned to help. Bellcomm, part of Bell Laboratories, assisted with the overall systems planning. GE was charged with overall testing and checkout. Later, after the disastrous Apollo fire, the Boeing Aircraft Co. was brought in to keep track of the intermediate stages—ties among the mechanical, hydraulic, electrical, electronic, and other systems.

Most of the prime contractors were aircraft and missile companies, accustomed to analog instrumentation and controls. The venture into space would require on-board equipment compatible with the experience of aviators turned astronauts. Moreover the equipment would have to be designed for in-flight repair if needed, which meant that failure detection and diagnosis was essential. Thorough and rapid checkout of tens of thousands of connections and signals would also be required on the launch pad. When it appeared that digital computing was the only way to run the spacecraft and the checkout, most of the subsystem designs were forced toward digital techniques.

Feedback from astronauts encouraged

As program elements were committed to design and development, NASA instituted a uniquely personal system of feedback from the very people who would use the equipment—the astronauts themselves. This practice made for useful, though oddly disturbing, effects on equipment design. The first group of seven astronauts consisted mostly of experimental test pilots. They expected to fly the spacecraft, rather than be flown in it.

The next nine astronauts were essentially flying engineers and contributed considerably to the technical directions being taken, although some, on their first visits to the Instrumentation Laboratory at the Massachusetts Institute of Technology in Cambridge, where a digital Apollo guidance and navigation computer was being developed, threatened that once they got up there, they would "turn that thing off." Ultimately a design was devised that permitted each procedure the computer was about to execute to be displayed for review by the navigator or pilot, giving him the option of telling the computer to proceed.

With the multiplicity of technical approaches encouraged by NASA, and with contractors and subcontractors layered many tiers deep, NASA field centers were kept aware of technical and program information via technical liaison groups, tracking information, instrumentation, and guidance and control. A huge computer data base accessed by remote terminals became a model for technical information storage and retrieval.

Nevertheless, it was tight control, centered in a few specific, responsible managers, that accomplished the system integration. For example, Mr. Low made Chris Kraft, his director of flight operations for the Johnson Space Center, responsible for the entire software development, ensuring that from the systems point of view the spaceborne and ground-based software could work together. What's more, one of Mr. Kraft's operations chiefs, Bill

Evan Herbert Contributing Editor

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Tindall, was assigned to the Spacecraft Program Office and developed logic diagrams for every operation that might take place during an Apollo mission. These logic diagrams led to the proper use of each system, fed back into the system design, and were the key to the operations manuals for each flight. "Without them I doubt whether we would have landed on the moon with Apollo 11 when the on-board systems appeared to be overloaded and a ground-based controller told the astronauts to ignore the overload signals," Mr. Low said.

The strong influence of a computer

A single subsystem, the Apollo guidance and navigation computer, influenced the decisions that ultimately were made about the moon. Because the computer was at the heart of both the main spacecraft and lunar module that would be used, it had inside-out influences on most of the other subsystems with which it interfaced. In a system like Apollo, designed to facilitate and support manned space flight, the interfaces are not only between hardware and hardware and hardware and software, but also between hardware-software and human beings.

Different specialists had different ideas about how to go about beating the Soviets to the moon. "Some of these were really hairy," NASA's Deputy Administrator Robert C. Seamans recalled, "like shooting equipment to the moon until everything was up there to be assembled into a spacecraft by the lunar crew for its return to earth." The concept of a lunar orbit by the main spacecraft, to be followed by a rendezvous with a lunar module, also seemed farfetched when it was first advanced by John C. Houbolt of the Langley Research Center in Hampton, Va. But the success of this concept hinged on precise guidance and navigation of both the command and lunar craft.

NASA's Management Council assessed the probability of success of a mission plan based on lunar orbit and rendezvous and urged its adoption. The decision to proceed was announced in July 1962. By October the Grumman Corp. had won the contest to build the lunar excursion module (LEM), which would become part of project Apollo.

There was no precedent for the vehicle Grumman was to build; it was not an aeronautical but purely an astronautical subsystem. And within that system Grumman wanted its own guidance and navigation computer. NASA insisted that both the command module and the LEM must have identical computers.

Later, on Apollo 13, as former astronaut Jim Lovell remembers, this decision to engender standardization was a saving grace. When the explosion of an overpressurized cryogenic oxygen tank damaged an adjacent fuel cell, almost everything in the command module, including the computer, was shut down to conserve the little remaining electric power. The LEM was used as a lifeboat until the crippled Apollo could be maneuvered onto a free return path to earth. To restart the command module computer, the LEM computer transferred needed information on position, velocities, and length of time in space.

The tricky business of interfacing

The MIT Instrumentation Laboratory team developing the Apollo guidance and navigation computer had its own interface design philosophy. Fortunately it was one firmly supported by NASA, for the computer electrical interface design was frozen before that of many other subsystems.

The MIT interface objectives that were to prevail stated: standardize as much as possible, use simple circuit configurations, develop wide but uniform specification limits, and use low pulse-repetition rates and duty cycles. These approaches made interface control documents more difficult to negotiate, but anticipated systems-integration problems hard to correct later.

Because the computer processed pulses by cycle stealing (processing many inputs at the same time), it risked being saturated. So one objective of the interface negotiations was to keep the data rates low. A limit of 3.2 kilohertz for the input/output counters was set. The number of interface circuit types was held to four, thus increasing reliability by extensive use of standard circuits and yielding more experience with circuit limitations and operational peculiarities.

The concept of wide tolerances in the interface specifications allowed for compatibility with many circuits and reduced the criticality of circuit design. But Eldon Hall, who led the computer system project at MIT and is still with what is now the Charles Stark Draper Laboratory, cautions that the wide variation allowed in a specification sometimes frustrated the achievement of what appeared to be a desirable objective. The designers wanted to ensure that the interfaces would not be sensitive to pulse shape and would be required only to distinguish the presence or absence of a pulse. However, a few subsystems that interfaced with the computer required critical timing that used the rise and fall times of the pulses.

Managing interproject communication

Committees and design-review processes spurred communication among the engineers and organizations working on the Apollo systems. Typically the guidance and navigation committee met regularly to review interface-control documents, electromagnetic interference specs, the test plans of the Raytheon Co., which built the computer, and the test plans of AC Electronics, the prime contractor for the guidance and navigation subsystem.

As for design review processes, there were several within the computer subsystem project. A very formal design review by NASA looked downward through the overall Apollo system. This was followed by an equally formal MIT review, of drawings and specs that were to bear the NASA imprimatur upon release, performed jointly by the Instrumentation Laboratory and the support contractors. The composition of this team kept changing, sometimes consisting mostly of design engineers and at other times largely of production engineers. This fluctuation underscored the close cooperation required, because design, breadboarding, and prototype production went on in parallel.

When design changes were needed, the process proved cumbersome to manage because of the contractual arrangements that had been instituted to permit the chopping up of tasks into projects running in parallel. Sometimes the process became an open loop; contractual details were processed through a different channel from the documentation for design changes. One area that needed elaborate procedures for control and documentation was software development. Because there were different Apollo flight mission programs to be stored in core-rope fixed memories, a "rope mother" was given complete responsibility for each computer program. Margaret Hamilton, who led the software development, said that the Apollo software systems still remain among the most elaborate ever produced. They affected almost every technical activity of the entire Apollo project. A hierarchy of review processes required changes to be signed off by a software designer, the rope mother, NASA, and every prime contractor and subcontractor who might be affected. The bureaucracy became so extensive that it almost required too much trouble to institute a software change.

Bureaucratic form and practices were inevitable in a project as gargantuan as Apollo. One of the management lessons seen in retrospect may be knowing where in each development phase one chooses the method and rigidity of control. ◆

3. THE POLITICS OF SPACE

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WHO OWNS WHAT? EARTH LAW FOR SPACE

Periodically throughout history mankind has had the opportunity to develop legal theories to meet the demands of advanced technologies. But advanced technology has only rarely produced whole new arenas for human interaction where no laws govern the interaction. Space is one such arena.

In the quarter century since the Soviet Union and the United States catapulted man into space, major areas of international law have become fair game for legal theorists. New laws controlling activities in space are desperately needed, but the hurdles in the way of creating them are enormous.

S. Neil Hosenball
National Aeronautics and Space Administration

Among the major hurdles are these:

- Exceptions taken to space treaties by countries that decline to be signatories to the treaties, or who wish to get around provisions in treaties they have signed. Equatorial nations, for example, are claiming control of any satellites placed in geostationary orbit over their lands even though an international treaty signed by over 90 nations permits no claims of sovereignty in space.
- Demands for restrictive treaties not likely to be viewed as acceptable to some major democratic nations. Many nations, including some Western European countries, are deeply concerned that direct-broadcast satellites will bring the undesirable transmissions of other nations into the homes of their citizens via inexpensive dish antennas.
- The concern of many nations over the inadequacies of current space treaties to control certain types of weapons from being tested, deployed, and used in space.
- Lack of international law to apply to private industry and to human interactions in space. Countries have by treaty, for example, surrendered any claim to territory on planets and celestial bodies, but they have retained legal control over their citizens. What happens if a citizen of one country assaults a citizen of another country in space, say? Which country's laws apply?

All of these areas represent virgin soil for legal doctrine. Two areas with a similar heritage are the law of the sea, stemming from navigational advances that permitted exploration of the world, and the law of airspace, necessitated by the ability to fly over territorial boundaries. At first competing interests in the sea and land were often resolved by conflict. In time disputes between competing interests were solved largely by the application of existing principles of sovereignty, the creation of customary international law, and the negotiation of international agreements.

The legal problems associated with outer space, however, are not subject to traditional sovereignty solutions. What is generally meant by the term "sovereignty" is that a state is self-governing; that it has authority to enter into diplomatic relations with other states and to make agreements with them in the form of treaties or conventions; and that it has freedom to control or dispose of its own territory and its own military forces. However, the acceptance of customary international law or any treaty by a state means that a state has surrendered some of its absolute supremacy or independence.

Current space law

With the three major characteristics that define sovereignty as guidelines, to what extent have states surrendered or retained sovereignty in space or over space activities? In December 1958, just one year after the Soviet launching of Sputnik I and less than two months after the establishment of the U.S. National Aeronautics and Space Administration, the United Nations established an Ad Hoc Committee on the Peaceful Uses of Outer Space. The purpose of this committee was to examine ways in which the UN could promote international cooperation in the exploration and use of space and identify any potential legal problems in this area.

After the committee had issued its report in 1959, the UN established a permanent Committee on the Peaceful Uses of Outer Space, which has negotiated and reported out to the General Assembly five treaties for signature by member states. The principal document, the "Treaty on Principles Governing Activities of States in the Exploration and Use of Outer Space Including the Moon and Other Celestial Bodies," promulgated in 1967, is considered the charter governing space activities. Over 90 of the 157 member states of the UN have signed it.

Perhaps the principal virtue of this treaty is its provision in Article II that outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation or by any other means." Throughout history nations have acquired territory through conquest or exploration. But because of the 1967 treaty, the United States did not claim sovereignty over the moon or any part of it after the lunar landing.

Despite the language of the 1967 treaty and the U.S. compliance with it, however, all the equatorial countries stated in the so-called Bogota Declaration of December 1976 "that the geostationary synchronous orbit is a physical fact linked to the reality of our planet because its existence depends exclusively on its relation to gravitational phenomena generated by the earth, and that is why it must not be considered as part of the outer space.

"Therefore, the segments of geostationary synchronous orbit are part of the territory over which equatorial states exercise their national sovereignty," the Bogota Declaration concluded.

It has been said that sovereignty is a trumpet blast employed to emphasize a state's honor, independence, and grandeur, and sovereignty is also invoked when a state does not wish to accept something under international law—particularly when the exception may yield significant economic, political, or national security advantage. The use of the geostationary orbit some 22 300 miles above the equator has obvious economic, political, and national security value. And when there are economic, political, and nationalistic issues, but no clearly established and enforceable law or treaty or clear sovereignty to resolve the issues, major international conflict becomes all too possible.

Technology is soon to be at the heart of a second crucial debate: what to do about the direct-broadcast-television satellites. The Soviet Union, the Eastern Bloc countries, and a significant number of developing countries assert that they have a sovereign right to control all information entering or leaving their country, whether it be print, radio, or television. They take this position notwithstanding that various declarations on human rights, including the Helsinki Accords, recognize the principle of free flow of information and the right of peoples to receive or impart information across national borders. They are particularly concerned about direct-broadcast-television satellites because of the economic, political, and cultural impact that television may have on their countries. At the 1982 General Assembly meeting a UN resolution establishing principles to be applied to direct-broadcast-television satellites, including one requiring consultation and agreement between the broadcasting and receiving states, was passed by a vote of 107 in favor of and 13 against, with 13 abstentions.

National security and the sanctuary concept

Potentially the most contentious area of all in space affairs is the military use of space. No arena better illustrates the looming clash of sovereignty notions than the desire of much of the world to apply international law before space becomes yet another realm for armed conflict.

So far, the superpowers have largely used their space technologies in the form of surveillance satellites to increase their security and that of the world. But many nations and individuals have been alarmed by the Soviet programs in antisatellite weapons and laser and particle-beam research. And recent U.S. attempts to keep up with the Soviet Union concern many citizens.

It is not that there is an absence of international law that can be applied to the military uses of space. There are many limitations on the sovereign rights of states, as well as provisions that reserve these rights to the states. Under the disarmament provisions in Article IV of the 1967 treaty, states that are party to the treaty undertake not to place in orbit any objects carrying nuclear weapons or other weapons of mass destruction, or to install such weapons on celestial bodies, or to station such weapons in outer space in any other manner. Article IV also forbids the establishment of military bases, installations, and fortifications and the testing of any type of weapon in the conduct of military maneuvers on celestial bodies. Article III of the 1979 Moon Treaty prohibits any threat or use of force on the moon or other celestial bodies. But none of these provisions prevent the superpowers from testing weapons in space, and as more nations become capable of placing satellites in space, the kind of bilateral negotiations process discussed by Ambassador Robert Buchheim on page 38 of this issue may not suffice to maintain space as a weaponless sanctuary.

Four more treaties followed the 1967 space treaty. For example, the Convention on International Liability for Damage (caused by space objects) makes states that are party to the treaty liable for damages resulting from space activities when such damage occurs on the earth or to aircraft in flight. Where injury or damage occurs between two artificial satellites in space, states are liable based on a fault theory. The Liability Convention does not, however, extend to damages caused by space activities on the moon or other celestial bodies, and the Moon Treaty specifically reserves the question of under what rule of law liability for damages occurring on the moon or another celestial body will be determined. Also, the Liability Convention does not provide for a binding award. Any award by the Claims Commission is only a recommendation, and each state reserves the right to decide whether to pay such an award. The Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space commits a state to waive its territorial sovereignty if an astronaut or spacecraft makes an unplanned landing in its territory. Under this treaty, the state is obligated to return the astronaut or spacecraft to the state of origin.

Authority over people and enterprise in space

Though states under the Outer Space Treaty may have given up their rights to claim territorial sovereignty in space, on the moon, or on celestial bodies, they have under Article VIII of the 1967 Outer Space Treaty retained their legal authority over their citizens when they travel into space or reside on the moon or other celestial bodies. Article VIII of the 1967 Treaty states that a nation launching objects into space shall "retain jurisdiction and control over such objects and over any personnel thereof." Further, according to Article VI of the treaty, the activities of nongovernmental entities in outer space—private industry, for example—"shall require authorization and continuing supervision by the appropriate state party to the treaty." From these provisions it appears that states have retained their rights to exercise their sovereign authority over their citizens whether in space or on the moon or on celestial bodies, just as they have the right to extend their sovereign authority over their citizens whether resident in their own territory or the territory of a foreign state here on Earth.

This bifurcation of territorial sovereignty from the exercise of sovereignty over citizens may cause many problems when outer space—the moon, other celestial bodies, or space platforms—become populated by human beings living, working, and carrying on commercial activities. On Earth two persons of different nationality, both of whom are in the territory of the United States, are subject to U.S. law because of U.S. sovereignty over its territory. If one committed a crime against the other, U.S. law

would apply notwithstanding that one may be a citizen of some other nation.

But if these same two were on the moon, where no nation has sovereignty, whose law would apply? Suppose they wanted to marry, or a child were to be born, or they wanted a divorce, or there were a question of custody of the children—the whole range of ordinary legal matters affecting the personal legal status of persons—what law would apply?

Extending international commercial law into space is also problematic. In space, whose law would govern the organizaton of business entities, the financing of such entities, and the commercial law applicable to business transactions between parties of different nationality?

Who should make space law?

In seeking to determine what law will govern activities in space, a fundamental question, perhaps more political than legal, is what kind of legal system will develop? Will space law be comprehensibly international, with a supreme international authority having enforcement jurisdiction, or will several states or other kinds of jurisdiction be carved out and permitted to develop laws of more or less local nature? Or will private conduct be largely unregulated, with legal principles and enforcement authority established to deal with particular situations as they arise?

Will the residents of a celestial body invoke Article III of the 1967 Outer Space Treaty, which says that activities in outer space including the moon and other celestial bodies shall be conducted in accordance with international law, including the Charter of the United Nations? The United Nations Charter contains in Article I (2) a provision that the friendly relations between peoples, which it is a function of the United Nations to promote, shall be based on respect for the principle of a people's right of self-determination. The self-determination principle may mean that every people has a right to determine whether it shall be an independent state or be joined to another state. The term is also used in the sense of the people's right to decide on the constitution under which they desire to live. The lack of territorial sovereignty combined with the principle of self-governing would seem to permit a space colony to develop its own laws or regulations independent of Earth. This appears to be true whether the colony were multinational in nature or composed largely of the citizens of a single nation on Earth. It would appear, for example, that a colony of U.S. citizens on the moon would be in a position to demand statehood as the 51st state of the Union by threatening otherwise to declare itself an independent nation.

These are just a few significant examples of the potential clash between sovereignty and international law as applied in space. As can be seen, there are theoretical problems that today may be largely academic. But as the exploration of outer space and the celestial bodies takes on a more permanent and extensive form, the structuring of a governing legal system may become a more practical problem.

The Ad Hoc Committee on the Peaceful Uses of Outer Space considered the establishment of an international authority to enforce the law applicable to outer-space activities but found that no autonomous intergovernmental agency should be created at this time nor should an existing agency be asked to undertake overall responsibility for space matters. In the past, legal rules, particularly with respect to novel areas of human activity, have not developed until there was a certain level of practice or agreement among the persons, entities, or states involved. The broadly phrased provisions of the Outer Space Treaty reflect the consensus on applicable legal rules that can be achieved at the present time. Except for the establishment of general principles, specific laws will have to follow the application of science and technology. Premature establishment of legal regulations as the result of inadequate information may serve to hinder rather than advance development of outer space. As ventures are launched into orbit and beyond, a body of law will follow that will attempt to preserve the development of outer space for the benefit of those living there and for all mankind. ◆

4. THE FUTURE OF SPACE

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Where will technology and politics lead us in space? The pages that follow include several articles by men intimately involved in setting the course of the U.S. space program. George A. Keyworth II, the science advisor to President Reagan, edges closer than he previously has to backing a permanently manned space station. "If U.S. citizens are asked to make an installment payment [on] a space station," he writes, "they should be allowed to share the grand vision of the future of space." One such vision, he adds, might include "a manned lunar station, or even manned exploration of Mars."

In another article, James Beggs, administrator of the National Aeronautics and Space Administration, foresees "a new era of truly international cooperative ventures in space" by the year 2008, when NASA will celebrate its 50th anniversary. Using the exploration and scientific settlement of Antarctica as a model, Mr. Beggs summons visions of multinational expeditions "charting pathways to the planets and the stars."

Concluding this section is an article by Senator John H. Glenn Jr., the former astronaut, who presents his personal agenda for U.S. space activities for the next quarter century. Calling for the establishment of a space infrastructure—including a permanently manned space station and a number of unmanned space platforms for scientific and applications purposes—Sen. Glenn details the next great leaps forward in space-based telecommunications, earth observations, and materials processing. He announces his personal support for renewed solar-system exploration and challenges the Government to support private enterprise and help reinvigorate U.S. space research and development. Finally, on the weaponization of space, he says, "It would be in the interests of both the United States and the Soviet Union to enter negotiations to reverse the trend toward and to eliminate any weaponization of space."

LOOKING AHEAD IN SPACE

In one of the classic examples of national vision and leadership in the postwar era, President John F. Kennedy anticipated and articulated the readiness of the United States to take a giant step in manned space exploration. The goal he offered was deceptively simple—a man on the moon by the end of the decade. And the nation responded—with ingenuity, enthusiasm, and dedication.

George A. Keyworth II
Executive Office of the President

We know now that Kennedy's call in 1961 for the Apollo program was a brilliant stroke. With astute political timing, he capitalized on three of the traditional strengths of the U.S. citizenry—its pioneering spirit, its technological expertise, and its competitiveness—to promote a renewed sense of national unity. In truth, the nation had little real reason to doubt its leadership then, especially in technology. But the launch of Sputnik in 1957 by a supposedly backward, unfriendly nation shocked and challenged the United States. That was the starting gun for its entry into the "space race" with the Soviet Union, a race that in retrospect turned out to be no contest at all. With hardly a look backwards, the United States, through the Mercury-Gemini-Apollo programs, led the world into the modern space age.

It was a classic example of a program that drew upon a society's resources. In particular, the U.S. space program was a product of the country's broad and advanced industrial and technological base. It drew on expertise in areas such as propulsion, materials, electronics, computers, space science, tracking, and navigation. Most important, it took advantage of the ability of U.S. engineers to integrate those technologies into reliable and efficient new systems. The United States entered the 1960s with space technologies in mind; it ended the decade with those and better technologies in hand.

Whether the age of space is measured from the half century since Goddard's pioneering experiments, or from the World War II rocket developments in Germany, or from the launch of Sputnik, it is clear that the United States has achieved a remarkable level of proficiency in space technology in a short time. It has successfully challenged a monumental frontier, and in the process it has reaped immense psychic, political, and technological rewards.

When I was a child, man's occupation or use of space was true fantasy. Today my own children take those capabilities for granted and wonder what other marvels the future will bring. Undeniably, the 1980s offer a broader set of options than the United States could have envisioned realistically just a generation ago. Today space technology and space operations are maturing fields.

Near-term space science and exploration

What can we foresee in the next decade and beyond for the U.S. space program? Let us look first at some of the more obvious elements, those things I would characterize as evolutionary developments.

First on my list are the purely scientific and exploratory missions. Although they no longer dominate our space activities as they once did, I confess that they still excite me the most. I'm especially intrigued by the Space Telescope, which may be the most important advance in observational astronomy since

Galileo's first crude telescope.

Ground-based observers have struggled for years to pierce the atmosphere with larger mirrors, faster emulsions, and electronic detectors. Their quest has taken them all over the earth in search of darker nights, clearer skies, and stiller air. In a few years, with a new perch above the atmosphere afforded by the Space Telescope, astronomers will get a truly spectacular view into a new dimension of the universe. Soon after, the launch of the Gamma Ray Observatory will permit a new spectral window on astrophysical phenomena, just as the advent of X-ray astronomy did in the 1970s. These two new scientific tools—the Space Telescope and the Gamma Ray Observatory—represent significant leaps in the sophistication of space-based instrumentation. I hesitate to predict what new horizons they'll reveal, but I am waiting with keen anticipation.

Man's understanding of the solar system has been growing over a span of two decades—from the early Ranger and Surveyor mooncraft, to the more recent spectacular observations of Saturn by Voyager II, to the exciting prospects for the Galileo missions to Jupiter. What began as an attempt to explore the nearer planets has evolved into a comprehensive program of scientific measurements and observations.

But in recent years these individual missions have become more complex and immensely expensive; as a consequence, they have become less frequent. In the past few years it became apparent that this stretching out of missions was threatening the ongoing vitality of the field of planetary science, especially its ability to attract new people. So in the past year the United States has taken steps to encourage simplified—and less costly—planetary probes so that it could afford more of them.

The planetary science community, making a transition from older exploratory programs to newer experimental ones, has devised a plan of affordable, effective missions that does not conflict with other research priorities. The Venus Radar Mapper, the first probe in a new program of planetary research, bodes well for renewed excitement in this field.

Observing and serving the earth

In another area, one of the earliest discoveries in the space age was the complexity of the magnetic and solar phenomena that surround the earth. Now the opportunity arises to use new space-observation techniques to see how those solar-terrestrial phenomena influence weather and climate as well as the growing global communications systems. Likewise, those same vantage points above the atmosphere—whether on orbiting satellites or on interplanetary probes—will continue to provide new insight into the evolution of our solar system and give us firmer knowledge of how the earth came to be.

In a more immediately practical sense, U.S. scientists will continue to take advantage of orbiting instruments to examine the earth, its features, and its resources. Broad-spectrum remote sensing of weather, ocean dynamics, biomass patterns, and mineral resources has reached sophisticated levels.

Communications is perhaps the most highly developed application of space hardware; the tremendous investments by commercial ventures, both in the United States and elsewhere, are evidence of how ingrained communications satellites have become in modern life. These applications to communications

will be increasingly influenced by such favorable factors as very high operational reliability, long service life, increasing satellite size, and increasing data-transfer rates.

The space shuttle: a wealth of possibilities

But by far the most important demonstration of the maturing space capability of the United States is the U.S. Space Shuttle, now a veteran of seven missions. Today the shuttle can almost routinely place large payloads in orbit; it also has the potential to revisit low-orbit payloads for maintenance and retrieval. It is important that the United States fully exploit these features in order to reap a substantial return on an immense investment.

Further, the shuttle is much more than a launch vehicle. It is a flexible manned space platform for research and development, with the potential of developing into an enormously capable space system. In fact, the shuttle–Spacelab combination is both larger and more capable than the Soviet Union's Salyut–Soyuz combination. To optimize its use of that shuttle–Spacelab capability, the United States can extend the length of time these vehicles can remain in orbit. Currently that period is limited to about seven days, but it could be extended to 20 or 30 days without great cost or risk.

The shuttle is also capable of placing large modules in a low-gravity environment. For years there has been talk about the potential for manufacturing ultrapure materials and undistorted crystal structures in space. We are about to see how real that potential is, with the joint McDonnell Douglas and Johnson & Johnson drug-manufacturing process leading the way. Obviously the shuttle's ability to revisit automated factories will be critical to the near-term potential of these emerging technologies.

Finally, access to space is increasingly important for national security. Satellites conduct regular surveillance of ground activity over much of the earth and enhance the military's ability to communicate and navigate. It is unfortunate that some of the more impressive examples of U.S. space leadership cannot be more widely appreciated because national security forbids their disclosure. The important point is that these technologies have reduced the possibility that the United States would be caught by surprise by either new deployment of weapons or mobilization of troops by an adversary. Particularly in a nuclear age, no one can tolerate surprises.

Competing realistically in space

So far, I've described future prospects in space development. I would characterize these projected developments as evolutionary activities. But the United States should consider revolutionary changes too. To do that, it must look at the realities of today and compare them with the realities that President Kennedy faced a generation ago.

In 1957 Sputnik was not a real challenge to the nation's security or economic well-being. But it did threaten the self-image and international prestige of the United States. Economically and militarily the country was secure, so it had no hesitation in responding to Sputnik with an ambitious space program to reclaim its national pride, to recapture its political prestige, and to reassert its technological supremacy.

That was a quarter century ago. Today the United States faces real—not symbolic—competition from other countries. It is confronted by an increasingly aggressive Soviet Union, which has continued a massive military buildup that transcends any reasonable requirements for its defense. At the same time an industrially revitalized Europe and Japan challenge the nation's economic leadership.

The response to this round of challenges is more difficult, requiring a long-term strengthening of the nation's base in science and technology. The United States needs new knowledge and new skills to make its products and services better, to expand markets through invention and innovations, and to increase the effectiveness of its military forces. Unlike the 1960s, when the country could more or less take for granted the adequacy of this base to serve its national needs, today it must make heavy and wise investments in its scientific and technical talent and facilities.

So in this new era of competition for resources, the nation is challenged to find the most effective and appropriate role for its space program. The question is not: Can the United States afford a large space program in light of these other priorities? Rather the questions are: How can the United States fashion a space program that addresses today's national aspirations and needs? How can it use its investments in space to bolster its science and technology base and to reignite the spirit of adventure that captured its people in the past?

Let me suggest two complementary approaches toward meeting this great challenge. Like an evolving company, the U.S. space program has options for both horizontal and vertical expansion. It can continue to build on experience and it can also move into newer, more exploratory, and inevitably less well-defined directions.

Let me offer one example of vertical expansion. I said earlier that the shuttle is far more than just a launch vehicle and that an effort should be made to take better advantage of its sophistication. At one time the shuttle was expected to meet almost all civilian launching needs. But I think that is a misutilization of its capabilities. Instead, smaller, simpler, and more mundane launching requirements should be met with existing expendable launch vehicle (ELV) technology.

President Reagan has encouraged development of commercial launching services that capitalize on past investment in ELVs, such as Atlas–Centaur, Delta, and Titan. Not only would such a development make the shuttle available for more elaborate missions, but it would also bring a desirable new element of competition into routine launching services. This competition should give foreign ventures in commercialized space launches a run for their money.

Several firms are emerging that combine entrepreneurial marketing skills with aerospace experience. It will be interesting to see how the forces of competition, with aggressive marketing and cost reductions in launch services, stimulate increased use of space in the future.

This balance between commercial ELVs and the shuttle could offer even more flexibility and security to U.S. space efforts. So I would characterize the evolution of commercial launch services as a kind of vertical expansion. Conversely, horizontal expansion would require revolutionary new ventures in space exploration. These would be the kinds of initiatives that open new frontiers, develop new technologies, or recapture the sense of national unity that Apollo did.

How far should man go in space?

Not surprisingly, now that the shuttle is becoming operational, there is more and more discussion about large new ventures in space—in particular, manned space efforts. Let me dismiss one factor that is frequently raised—the fact that the Soviets seem to have a more advanced man-in-space program. In truth, the Soviet effort reflects the relatively less sophisticated state of their technology, in terms of automation and equipment reliability. The United States, on the other hand, has shown how much can be achieved—and how much more cheaply—by using high tech-

nology to carry out many of the functions that would otherwise require hands-on operation.

The real question is not whether the United States should emulate the Soviet Union, but whether it can inject a new sense of vision into U.S. space exploration. The most often discussed and most immediate possibility is a manned space station, serviced by the shuttle and composed of modules supporting a broad spectrum of space activities. This was the original objective of shuttle development a decade ago, and the needed technology appears to be within reach.

However, any of the kinds of space stations being discussed would be expensive—costing many billions of dollars. I question the return on that kind of investment because it is not clear yet what would be done with the station once it were completed. Some people have jumped to the conclusion that I have a bias against a space station because I insist on a valid mission before making any commitment. That is not true. But I think it is time for us to take a broader look at where we expect the U.S. manned space program to go over the next quarter century.

Most advocates of a space station readily acknowledge that it is only an intermediate step in the more ambitious long-range goal of exploring the nearby solar system. If U.S. citizens are asked to make an installment payment in the form of a space station, they should be allowed to share the grand vision of the future of space—whether it is an orbital transfer vehicle to provide manned access to high geostationary orbits, a manned lunar station, or even manned exploration of Mars. Surely the Apollo experience has shown that the United States can be strongly supportive of ambitious new programs if the citizens share the vision and if they are convinced that important national needs are being served.

Exploring the future

The National Aeronautics and Space Administration is examining these various options, especially the space station, and its studies should provide the basis for important choices. But ultimately the major decisions about the nation's course in space must be based on a strong national commitment. Those decisions will necessarily involve considerations of cost, benefit to the nation, and impact on the overall space program. And most important, they will depend on how a major new program would influence the United States' ability to meet looming challenges to its economic future and its national security.

Even while the United States considers those larger space projects, there are several immediate steps it can take. It can, and must, fully exploit the shuttle-Spacelab concept and continue to involve the private sector in space and space-related activities. These steps are necessary if the nation expects to develop a sufficient industrial, economic, and scientific and technical base to continue to be the leader in space exploration. More important, these steps will also help maximize space capabilities over time. The United States is in an enviable position to take advantage of its leadership in electronics and space technology and to continue to build a rock-solid foundation for the next stages of the space program.

There is also one additional use of space that may come about in the near future and that could change fundamentally the way we perceive the world. I refer to President Reagan's proposal on March 23 that the United States devise a strategy that emphasizes defense over offense—in particular, defense against nuclear attack. Such an advanced defense system would almost certainly involve space technology.

One prediction seems safe enough. Space science, exploration, even defense, will increasingly be international in scope. This is consistent with our approach to other kinds of "big" science, which is growing too expensive for individual countries to continue to pursue on essentially parallel tracks. Just as many nations share the results of space science and explorations, it is time for them to share more of the financial responsibility, too. Otherwise the United States will be increasingly constrained in mounting the kinds of imaginative scientific missions that take advantage of developed space technologies.

Space is a place to be careful, but not to be timid. The present dialogue, even the controversy, is appropriate for a nation confronting difficult decisions in a difficult time. ◆

NASA'S DUAL CHALLENGE: SERVING YET STRIVING

With 25 years of leadership in space behind it, the National Aeronautics and Space Administration is at a crossroads as it faces the next quarter century. Organizations such as NASA are means to accomplish the ends of those who create and sustain them. Fundamentally, it is impossible to discern NASA's future evolution without knowing what path in space the United States will choose from among the many options available; the outlook for NASA depends on the goals selected by the Government for the next quarter century's space efforts.

Twice before, in 1961 and in 1982, U.S. Presidents proposed, and Congress agreed to, multibillion-dollar investments of public funds in a space project—first the Apollo program and then the U.S. Space Shuttle. Now NASA is hoping to develop a permanent, manned station in space.

This aspiration is a logical next step for an agency that, while accomplishing many unmanned science- and applications-program goals, has for two decades been nurtured by its manned projects. At the same time, NASA is attempting to deal with issues unlike any it has faced in the past. It is being asked to help commercialize broad sectors of space activity, to maintain a U.S. leadership position in the international space competition with Europe and Japan, as well as with the Soviet Union; and to work in close partnership with other civilian agencies, the Department of Defense, and the private sector.

Such relationships, to be effective, will require a very different NASA than now exists; thus, the challenge that faces NASA today is whether it can both develop a space station that is broadly useful to the country and make the adaptations required to encourage private-sector initiatives in space.

NASA's evolution: off to a fast start

What was unique about NASA in its first decade was the rapid mobilization into a single organization of high-quality technical and managerial personnel and expensive facilities, plus the coupling of that organization with a network of industry and universi-

John M. Logsdon George Washington University

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ty activities. The aim was to create for the United States a preeminent capability to operate in space. Although NASA opened for business in 1958, it was not until the May 1961 call of President John F. Kennedy for a space program "which promises dramatic results" that the space agency became transformed into a potent and aggressive technical organization carrying out a high-profile, politically driven mission.

At the peak of the Apollo program, NASA had a budget of $5.25 billion (equivalent to almost $19 billion in 1983 dollars), employed 36 000 people, and was supported by an industry and university team composed of 377 000 people, as well as facilities representing an investment of over $4 billion. The organization was dominated by development engineers who had an expansive view of the future in space. That orientation was appropriate for Apollo, but it has caused problems for the agency ever since.

Where to go from Apollo

After the moon, what? NASA's answer to that question was first made public at almost the same time as the initial lunar landing. At the Apollo 11 launching, Vice President Spiro T. Agnew, who was heading a top-level review of post-Apollo space policy for President Richard M. Nixon, told the assembled news reporters that "we should articulate a simple, ambitious, optimistic goal of a manned flight to Mars."

NASA found this prospect quite appealing. Within a few days the agency had added a manned Mars mission during the 1980s to the plans it had been developing for several years. Those plans already called for a 12-person space station to be placed in earth orbit by 1975; a 50-to-100-person space base by 1980; a permanent manned base on the lunar surface in the same year; a "grand tour" of all the outer planets of the solar system by unmanned spacecraft; and, almost incidentally, an earth-to-low-orbit reusable launch vehicle to resupply the space station and to rotate its crews. That vehicle was called the space shuttle.

Implementing this plan, NASA contended, would "expand this nation's capacity for space flight as far as foreseeable development in technology will permit." While NASA's leaders may never have expected approval of an early Mars mission, they did hope to develop a space station and a space shuttle during the 1970s, and the Mars objective gave a focus and a justification that were otherwise missing.

This ambitious set of proposals was a reflection of what NASA had become during the Apollo years: an organism that was more responsive to its own internal technological momentum than to externally developed objectives. However, the nation's political leaders rejected NASA's vision of a space program that was driven primarily by technological feasibility. That rejection has been frequently reaffirmed in the years since then. After Apollo, the United States decided that it wanted a space program tailored to scientific, economic, and national security payoffs. President Nixon and Congress concluded that the motivations that undergirded NASA's first decade—national prestige, national pride, and symbolic competition with the Soviet Union—were no longer of top priority.

However, President Nixon did not want to end the manned space-flight program; he believed the astronauts were valuable for national morale. Also, there were beliefs among those concerned with space policy—accepted more on faith than evidence—that the space frontier was just opening, that there were a variety of future missions with high payoffs for society, and that human involvement in space operations was likely to be important.

Given these factors, the space shuttle program emerged as a logical next assignment for NASA. Although there would be no

space station to which the vehicle would "shuttle," a reusable launcher could be justified in terms of increasing the capability for, and lowering the cost of, all forms of space activity; making access to orbit routine; keeping human crews involved; and preserving the option to develop a space station at a later time. Moreover, the shuttle was intended to be a national space project, serving civilian and military users alike, and not just a NASA launch vehicle.

The space shuttle reveals NASA's predilections

For most of the past decade, NASA has acted as if it had forgotten the reasons why the shuttle had been approved and has tried to run the project as if it were another Apollo program. NASA had projected a busy future for the civilian and military space program of the 1980s. It had argued that the space shuttle would lower the cost and increase the flexibility of operating in space and could be developed on a budget low enough to allow many other NASA science and applications programs to thrive. Considerations of user compatibility, technical simplicity, minimizing operational costs, meeting development schedules, and staying within an approved budget were submerged as NASA's engineers became fully engaged with the shuttle and found out just how complex a development task it was. The vehicle that has been created is much closer to a high-performance, but temperamental, Jaguar than to the "space taxi" that was promised.

The technical challenges of the enterprise dominated NASA's existence during the 1970s, and many of the agency's other projects and proposals were deferred in order to procure the funds required to solve those challenges. Only as schedules slipped and budgets increased did NASA begin to get the project under firm control and shape it to the uses for which it had originally been intended. This is a task that continues today.

NASA is in 1983 an institution with an almost schizoid character. Its leaders talk of commercialization, user-friendly systems, smaller spacecraft for solar-system exploration, and the need for a space station to support the needs of industry, the scientific community, and the military. Much of NASA's heart, however, still seems to be linked to the excitement of manned missions and astronaut heroes, to the opportunity of developing large space systems, and to visions of exploring the planets with both men and machines.

NASA in 1983 is also still a highly capable technical organization, although it has shrunk in size and perhaps competence since its heyday. The current work force is just over 21 000, down almost 40 percent from 15 years ago, and this year's NASA budget has less than 40 percent of the purchasing power of its 1966 allocation. The NASA field centers remain top-flight scientific and engineering organizations. Many of the NASA staff members who were attracted as young engineers and managers by the Apollo buildup 20 years ago are still there in mid-career, still eager to tackle challenging technical problems. If NASA does not offer those challenges in the next several years, then its best people may be tempted to switch to other work and bright new graduates will not be attracted to the agency; indeed, such a "brain drain" may already have begun. The NASA facility and equipment base is not as up to date as one might like, but it still represents an impressive capability for undertaking new space projects.

The space station: an attractive prospect

Although others have suggested a variety of objectives for NASA in the coming years, the organization itself has chosen to propose a space station as its next major project. What remains to be decided is whether the nation wants to use NASA's capabilities for such an enterprise.

The notion that a manned orbital facility of long duration is an essential element in the development of a national space capability has been around for more than 25 years; what has changed over time is the reason given for why such a facility is essential. The current rationale is mixed: the station is seen both as a research and development laboratory for exploring scientific questions and technological potentials and as an operations center involved with on-orbit assembly, testing, deployment, orbital transfer, data processing, and spacecraft servicing and storage. This rationale describes the station and the long-

duration presence of humans in orbit as elements of a space "infrastructure"—that is, the supporting capabilities required to accomplish various missions and objectives. There is even a willingness again to talk of the space station as a crucial step in the manned exploration of the solar system.

Developing a space station is an attractive prospect to NASA for a number of reasons. First, it may be the only major new program on the horizon that has a reasonable chance of Administration and congressional backing. Second, it would keep usefully occupied those technical staff members of NASA who are winding up their work on the shuttle. Third, a station fits into the current concept of an appropriate undertaking for the space agency: it is a means to multiple ends, not an end in itself. In a sense, a NASA space station project aimed at serving all those interested in operating in space is a bullish approach to creating a long-term partnership of the public and private sectors for space exploitation—but this approach will work only if NASA also changes and becomes an effective partner to the private sector. Whether or not NASA gets the go-ahead sign for the space station, it is clear that a major theme of the nation's space policy through the next decade will be the creation of such a partnership.

NASA's role in helping private enterprise

The Reagan administration's space policy announced last year gives equal weight to preserving "United State leadership in critical space activities" and providing "a climate conducive to expanded private sector investment and involvement in space activities." A recent National Academy of Public Administration report called for NASA to make a "major commitment to the commercialization of space technology," a commitment that would require a much more intimate relationship between NASA and U.S. business than has existed historically.

For NASA to be an effective partner of private enterprise in space, a substantially different organization from that which now exists—and probably some significant changes in NASA's authority to engage in joint public-private activities—will be needed. Business analysts and cost accountants will have to join engineers on the NASA staff, and the agency's R&D priorities will have to be based as much on the advice of industry and other users of space as on the next interesting technological problem. It will be hard to maintain the astronaut-as-hero image when a corporation booking a major share of the space on a shuttle flight can nominate someone to ride along with the payload, as the McDonnell Douglas Corp. has done already.

Although NASA has made an honest effort in the last few years to assist those who see a potential for profitable investments in space and to reduce the risks associated with such investments, this role still appears to be assumed grudgingly. This will have to change if one of NASA's roles is to provide the foundation for private entrepreneurs who wish to exploit space technology.

Routine use of outer space as a place to work will not have the pizzazz of lunar and planetary exploration. In this environment, NASA will be only one, and not necessarily the dominant, U.S. actor in space. What NASA does best is research and development in space technology and demonstration of the feasibility of various space systems. Other Government agencies and other private-sector organizations are likely to emerge as the operators of those space systems, whether they be launch vehicles, earth-observation spacecraft, space factories, or communications satellites. National space activities in the next quarter century will not be dominated by NASA anywhere near to the degree they have been in the past.

Competing with Europe and Japan

At the same time, the United States will be only one among many nations in the world with a sizable space effort. A major finding of a recent U.S. Office of Technology Assessment study of space policy was that "unless the United States is prepared to commit more of its public and private resources to space than it does now, it will lose its preeminence in space applications during the 1980s. Both technological and commercial leadership are at stake," the study noted.

The U.S. space program of the 1960s was shaped by strategic political competition with the Soviet Union; the program of the 1980s and 1990s may be as strongly influenced by economic competition with Europe and Japan. The Academy of Public Administration recognized "the constructive and catalytic role space efforts can play in sustaining the technological and economic competitiveness of large sections of American industry."

If space becomes a major arena of international economic competition, then NASA's R&D efforts will have a higher priori-

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ty than they do now and more of the agency's technical capabilities will be engaged in economically oriented efforts. Other advanced countries, particularly France and Japan, seem to have identified space technology as one of the underpinnings of economic success several decades from now, and these nations are making the early investments required to assume a leading role in space.

By its actions two decades ago in creating NASA and seeking space preeminence, the United States got a head start in the race to create payoffs from space; the decision to develop the space shuttle sustained this leading position. If the benefits of past investments are to be realized in the next 25 years, a NASA—and a nation—much more oriented to technological and economic benefits and more sensitive to besting its international competitors must evolve, almost certainly requiring a close conjunction of the leading sectors of U.S. business and the Federal government.

Merging with the military?

The U.S. space program now includes an increasingly large military effort with its own objectives, budget, and institutional structure. There has been a much greater recognition of the strategic importance of space by the top management of the Department of Defense and the Air Force. Increasing militarization is the most important space development of the last decade. This article does not address military space activities in great detail, although they could well become the dominant part of the Government's involvement in space. As the militarization of space continues, NASA will certainly be called upon to provide R&D support, but the Department of Defense is likely to keep most of its space-related activities in-house. However, if NASA does not develop strong links with the private sector, the agency eventually could be swallowed up by the Department of Defense. Control over staff and facilities would then be transferred from civilian to military authority.

There are substantial political arguments for maintaining a separate civilian space agency even if the growth of the military program continues. There are benefits to be reaped from the ability to engage in international scientific cooperation and economic competition, to use NASA programs and representatives as symbols of positive national achievements, and to conduct an open U.S. space program while at the same time continuing a classified national security effort. Merging NASA and DOD space efforts would mean losing those benefits.

An uncertain future

It is possible, on the basis of recent trends, to conclude that NASA, as a unique experiment in developing a new technological sector by a civilian agency of Government, is winding down; that the institution is fast fading from neglect, misuse, and militarization; and that it could not effectively mobilize the resources to meet a new external challenge.

Another possibility, however, is that NASA will not receive a new systems-development assignment such as the space station; instead, it will obtain the resources needed to maintain itself as an R&D agency with modest science and application efforts. Such an organization would be much leaner, make fewer headlines, and have less political visibility, but it still could be quite effective in achieving important objectives.

Perhaps the most desirable option is for NASA both to remain a large and capable R&D organization and to evolve into an effective partner of private-sector space interests. It is highly unlikely, however, that NASA will ever reemerge as the kind of highly mobilized entity it was during the Apollo era. For the last 25 years, NASA has served this nation well; unless the United States turns away from space in the next 25 years—and this is not likely—it is probable that NASA, shaped by an exciting adolescence but adjusting to the more restrained expectations of adulthood, will continue to serve the United States well in the years to come. ◆

SPACE TOMORROW: THE ANTARCTICA MODEL

The people of the United States are, by both history and inclination, pragmatic and practical. Yet they have always been a people with a vision. Some have called this vision simple and sometimes naive. Yet it is that vision that has so often led the United States to dare and achieve. Americans have been pathfinders, farsighted enough to set goals and sights on points beyond, yet imaginative enough to figure out how to reach them.

The U.S. approach to opening space, the last and greatest frontier, has been solidly grounded in the American experience. It has relied on realism, imagination, vision, daring and, in Alexis de Toqueville's words, "the strength and reason of the individual."

Americans have never shirked reality, with all its dangers and all its opportunities. And perhaps that is why the United States stands now on the threshhold of what will surely be a magnificent new era in space. Those who will reap the rewards of that era will be those, who, as Pericles once said, have the clearest vision of what is before them, glory and danger alike, and, notwithstanding, go out to meet it.

If the past is any guide, the United States will be in the forefront of that great adventure. It will go forward with those who share its vision of the future.

NASA's contribution to technology

The National Aeronautics and Space Administration, the agency that spearheaded the nation's achievements in space, is now celebrating its silver anniversary. Since 1957, when Sputnik's faint beep-beep from space shocked the United States into affirming its national pride, resulting a year later in the creation of NASA, the agency has been the driving force in maintaining U.S. preeminance in space and aeronautical technology. Indeed, NASA has played a vital role in stimulating new technology development across the board. And in doing so, it has helped build national economic strength at home and competitive strength abroad.

Whole new industries, such as computer science, solid-state electronics, medical electronics, and communications satellites were advanced largely as a result of NASA's research and development activities. New jobs and economic growth have sprung from U.S. investment in high technology. Technology drives the United States.

And it also drives the rest of the world. The Europeans and the Japanese are developing high technology that rivals U.S. expertise. And with it has come the entry of these nations into space. The Soviet Union has an impressive space capability. Brazil, India, Indonesia, the People's Republic of China, Canada, and

James Beggs
National Aeronautics and Space Administration

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others have entered the space arena. And the list of countries who view space as essential to their activities on Earth is growing longer every day.

Small wonder, then, that when the editors of *Spectrum* asked me to write this piece on where the space program will be in the year 2008, NASA's golden anniversary year, two obvious considerations came immediately to mind. They were the growing number of spacefaring nations and the increasingly international aspect of space activities.

Internationalism in space's future

Looking another 25 years down the road, I believe these two factors clearly indicate that we are entering a new era of truly international cooperative ventures in space.

My friend, the late Wernher von Braun, was both a visionary and a pragmatist. He foresaw this trend. When speaking of the future of mankind in space, he used to draw an analogy between the exploration of Antarctica and the exploration of space. I don't know whether his analogy is valid. But I believe it serves as a useful philosophical framework for thinking about the future in space.

Dr. Von Braun pointed out that Antarctica and space have three things in common. Both are far away and hard to reach. Both are hostile to human life. And both require complex logistical planning and operations if people are to get to their destinations and survive.

Expeditions to the South Pole by the Norwegian Roald Amundsen in 1911 and the British explorer Robert Scott early in 1912 were carried out for reasons of national prestige, not unlike our Apollo program.

But permanent settlements in Antarctica came about only because of the dawn of a new technology, that of the airplane, in the late 1920s. By then aircraft had become reliable enough to be used for long flights over very hostile territory.

With planes it became possible not only to map the huge island continent, but also to supply and resupply bases with equipment and supplies and to rescue people, should that be necessary. Today the ice of Antarctica is dotted with permanent bases built by many nations, all dependent for their survival primarily on the use of aircraft.

What are the enabling technologies that would bring us back to the moon, or to Mars, or to the asteroids, to explore at first, and later, perhaps, to establish permanent bases? Clearly, they would have to be those technologies that would be part of a permanent earth-orbiting space base and the orbital-transfer vehicle that could be developed with it. An orbital-transfer vehicle is a rocket based at a permanent space base in orbit. Together with lunar landing vehicles, it could make possible further manned exploration of extraterrestrial bodies.

With the U.S. Space Shuttle the United States stands on the verge of realizing one of mankind's oldest dreams, building a permanent manned space base in orbit and, from there, charting pathways to the planets and the stars.

Back to the moon

I firmly believe that, if such a base were in orbit by the year 1991, the United States would be back on its way to the moon by the year 2000. And by 2008, when NASA will be 50 years old, other nations will have joined in this endeavor, as they have joined in the exploration of Antarctica.

We are fortunate indeed to live in an age of great adventures. The 1920s and 1930s saw the exploration of the polar regions of the earth. In the 1940s and 1950s the exploration of the depths of the ocean began to bear fruit. Humankind is now embarked on the greatest adventure of all: the exploration of the solar system, the galaxies, and the universe.

This enterprise will not only occupy the human race for centuries to come, but it could also very well serve as the catalyst for peaceful cooperation and true brotherhood for all the nations of the world.

The challenges and opportunities are boundless. If we are confident, bold, and determined not to let them pass us by now or in the future, the bounties could dwarf those of all previous eras of exploration combined.

Arnold Toynbee once wrote that "civilization is a movement and not a condition, a voyage and not a harbor."

Since the dawn of civilization we have traveled a long road. But, to paraphrase Robert Frost, we have miles to go before we sleep. In the face of cosmic forces, human beings have embarked on a voyage that has already achieved astonishing things. We have done so through sheer force of will, with courage and with faith in the future.

If we continue in that spirit, I have every confidence that we will, one day, extend our reach to the stars. ◆

TO PROBE FURTHER

General

Among the many newsletters, magazines, reports, and books that report on space-related issues are the following:

- A special issue of *Futures: The Journal of Forecasting and Planning* titled "Space—Past, Present, and Future," Vol. 14, no. 5, October 1982. The journal is published six times a year by Butterworth Scientific Ltd., 88 Kingsway, London WC2b 6AM, England.
- A special issue of *Sky and Telescope* for October 1982 commemorating the 25th anniversary of the space program that is an excellent reference for the history of international space activities.
- *Aviation Week and Space Technology*, McGraw-Hill Publications, 1221 Avenue of the Americas, New York, N.Y. 10020; telephone 212-997-4117.
- The TRW Space Log annual catalog *Twenty-Fifth Anniversary of Space Exploration: 1957–1982*, a guide to the status and classification of all launched satellites from TRW Electronics and Defense, One Space Park, Mail Station E2/5062, Redondo Beach, Calif. 90278.
- A report by the Senate, *Civilian Space Policy and Application*, 1982, that evaluates present and possible future directions of space applications, from the Office of Technology Assessment (OTA), Washington, D.C. 20510.
- *NASA Pocket Statistics*, a summary of the NASA program goals and objectives, major mission performance, USSR spaceflights, U.S. and USSR space records, and selected technical, financial, and manpower data. Write to the Management Support Office, Office of Management, NASA, Washington, D.C. 20546.
- The proceedings and conclusions of the 1981 Aspen Institute for Humanistic Studies conference on space activities, "Global Implications of Space Activities," from the American Institute of Aeronautics and Astronautics (AIAA), 1633 Broadway, New York, N.Y. 10019; telephone 212-581-4300.
- *Beachheads in Space: A Blueprint for the Future*, by Jerry Grey, Macmillan Publishing Co., New York, 1983.
- *Cosmic Discovery: The Search, Scope, and Heritage of Astronomy*, by Martin Harwit, Basic Books, New York, 1981, a general reference to discoveries of phenomena throughout the universe.

A number of groups can provide general and specific material about space. The Planetary Society, for example, was formed to encourage planetary exploration. It can be contacted at P.O. Box 91687, Pasadena, Calif. 91109.

The IEEE Aerospace and Electronic Systems Society holds meetings and conferences and exchanges information with experts in such fields as flight instrumentation, electronic ground-support systems, and satellites. For more information, write the IEEE Aerospace and Electronic Systems Society, 345 E. 47 St., New York, N.Y. 10017.

Particularly helpful is the American Institute of Aeronautics and Astronautics, a nonprofit society of engineers and physicists in the aerospace business. It holds meetings and publishes *Astronautics and Aeronautics*, a monthly magazine covering current topics in the field. Its executive branch office is at 1633 Broadway, New York, N.Y. 10019; phone 212-581-4300. The AIAA library, Technical Information Services, has literature on aerospace activity at 555 W. 57th St., New York, N.Y., 10019; telephone 212-247-6500. New material from the library is published semimonthly in the *International Aerospace Abstracts*.

The Video Vision Association produces laser video disks about specific NASA launchings including the U.S. Space Shuttle, the Voyager, and the Apollo missions. The disks contain film clippings and diagrams covering all aspects of the missions. Obtainable from the Association at 37 E. 21st St., New York, N.Y. 10010, they are produced by the center of Aerospace Education at Drew University, Madison, N.J. 07940.

1. CROSSROADS IN SPACE

Humanization: man or machine?

Two informative NASA technical memorandums on automated space activities are "Self-Replicating Systems—A Systems Engineering Approach," by Georg von Tiesenhausen, July 1980, and "Management and Control of Self-Replicating Sysems: A Systems Model," February 1982, by Dr. von Tiesenhausen and Wesley A. Darbro.

For a detailed analysis of the political implications of landing on the moon, see *The Decision to Go to the Moon: Project Apollo and the National Interest*, by John M. Logsdon, Chicago University Press, Chicago, 1976.

Militarization: peace or war?

The New High Ground, by Thomas Karas, describes the increasing use of space for military operations [see Book Reviews, p. 9].

Transcripts of the hearings on arms control and the militarization of space, which took place before the U.S. Senate Committee on Foreign Relations' Subcommittee on Arms Control, Oceans, International Operations, and Environment on April 14 and May 18, 1983, can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

An environmentalist's view of the threat of the militarization of space is given in a paper, "Global Geopolitics" by Daniel Duedney, Worldwatch Institute, 1776 Massachuetts Ave., N.W., Washington, D.C. 20036, 1983. See also his booklet *Space: The High Frontier in Perspective*, Worldwatch Paper no. 50, August 1982.

For the Department of Defense booklet, *Soviet Military Power: 1983*, with a preface by Defense Secretary Caspar W. Weinberger, write the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Two volumes prepared by SIPRI (Stockholm International Peace Research Institute) are major references on technology of space warfare: *Outer Space—Battlefield of the Future?*, 1978, and *Outer Space—A New Dimension of the Arms Race*, 1982. Both can be obtained through Crane, Russak & Co., 3 E. 44th St., New York, N.Y. 10017.

Internationalization: harmony or tension?

For information on the Soviet space program, see the Senate Committee on Commerce, Science, and Transportation's report entitled *Soviet Space Programs: 1976–1980*, U.S. Government Printing Office, Washington, D.C. 20402, 1982. The report covers supporting vehicles and launch vehicles, political goals and purposes, and international cooperation in space.

A technical memorandum summing up reports of an OTA workshop and covering internationalization, space applications, UN treaties, and militarization is *Unispace '82: A context for in-*

ternational cooperation and competition, Office of Technology Assessment, Washington, D.C. 20510.

The United Nations periodically publishes pamphlets on the affairs of the Committee on the Peaceful Uses of Outer Space, available from the Office of Public Information, United Nations, N.Y. 10017; telephone 212-754-1234.

For more information on past and current cooperative space efforts, see *Space activities of the United States, the Soviet Union, and other launching countries/organizations: 1957–1982*, prepared by the Congressional Research Service and based on research by Marcia Smith of the Library of Congress. Write the U.S. Government Printing Office and request document no. 19-550-0.

Commercialization: high time for profits?

The present state and possible future directions of satellite communications, land remote sensing, materials processing in space, and space transportation are evaluated in *Civilian Space Policy and Applications*, compiled at the request of the Senate Committee on Commerce, Science, and Technology and available from the Government Printing Office.

EOS (for electrophoresis operations in space), a description of the McDonnell Douglas materials-processing experiments, can be obtained from the McDonnell Douglas Astronautics Co., St. Louis Division, St. Louis, Mo. 63166; telephone 314-232-0232.

Space Business News, a publication devoted exclusively to the business use of space, is published twice a month at 1401 Wilson Blvd., Suite 1000, Arlington, Va. 22209.

The economic benefits of the space program are discussed in *Space Benefits: The Secondary Application of Aerospace Technology in Other Sectors of the Economy*, prepared by the program for Transfer Research and Impact Studies, Industrial Economics Division, Denver Research Institute, University of Denver, Denver, Colo. 80210.

2. SPACE TECHNOLOGY

A monthly magazine that gives recent developments in telecommunications is *Satellite Communications*, 6430 S. Yosemite St., Englewood, Colo. 80111; telephone 303-694-1522.

The future of remote sensing is discussed in Vols. I and II, 1982, of the IEEE digest of *1982 International Geoscience and Remote Sensing Symposium*, IEEE, 345 E. 47th St., New York, N.Y. 10017.

"Technology components of solar arrays for space platforms," a paper delivered by Klaus Bogus of the European Space Agency at the Sixteenth IEEE Photovoltaic Specialists Conference in 1982 in San Diego, Calif., assesses current space photovoltaic technology activities in Europe related to future space platforms. During the same conference, John S. Monck of the Jet Propulsion Laboratory in Pasadena, Calif., presented "New Directions in Solar Array Development." The conference proceedings, IEEE publication no. CH 1821-8, is available for $54 for members, $108 for nonmembers, from the IEEE Service Center, 445 Hoes Lane, Piscataway, N.J. 08854; telephone 201-981-0060.

Difficulties and differences early in the space program, especially with respect to "man-rating," are outlined in NASA's sp-4201, *This New Ocean: A History of Project Mercury*, by L.S. Swenson Jr., J.M. Grimwood, and C.C. Alexander, available from the U.S. Government Printing Office, Washington, D.C. 20405.

By 1972, when design of the shuttle began, its program-management aspects were well established; they are described in "Space Shuttle Orbiter: A Reliability Challenge and Achievement," by V.P. Ostrander in the 1982 proceedings of the Annual Reliability and Maintainability Symposium, pp. 468-73, available from the IEEE Service Center at the above address.

Methods for reliability designing of spacecraft are given in "Lessons from NASA," by Walter C. Williams, *IEEE Spectrum*, Vol. 18, no. 10, October 1981, p. 79.

3. THE POLITICS OF SPACE

For a more complete picture of foreign space policy, see *International Cooperation in Space*, by Arnold W. Frutkin, Prentice-Hall Inc., Englewood Cliffs, N.J., 1965.

Specific information on space law can be found in the Senate Committee on Commerce, Science, and Transportation's three-volume set of *Space Law: Selected Basic Documents*, second edition, U.S. Government Printing Office, Washington, D.C. 20402. See also the *Journal of Space Law*, published by the University of Mississippi Law Center, University, Miss. 38677.

An overview of international space law is given in *The Modern International Law of Outer Space*, by Carl Q. Chrystol, Pergamon Press, Elmsford, N.Y. 10523.

Readers can obtain a copy of "Activities in space, a matter for international regulation," by Robert W. Buchheim, in the January 1983 *Vital Issues*, by writing to the Center for Information on America, Washington, Conn. 06793. The center is a nonprofit, nonpartisan educational corporation.

Questions regarding the French space program should be directed to the Centre National d'Etudes Spatiales, 129 Rue de l'Universite, Paris 75007, France.

Information on the European Space Agency (ESA) can be obtained from Agence Spatiale Europeene, 8-10, rue Mario-Nikis, 75738 Paris Cedex 15, France, or from its Washington office at Suite 1404, 955 l'Enfant Plaza, S.W., Washington, D.C. 20024.

4. THE FUTURE OF SPACE

To find out what NASA has planned for the next 20 years, see *Planetary Exploration through the Year 2000—A Core Program*, part one of a report by the Solar System Exploration Committee of the NASA Advisory Council, 1983, U.S. Government Printing Office, Washington, D.C. 20402.

Gerald K. O'Neill, a professor of physics at Princeton University, has written two books on space colonies, space manufacturing, and their future prospects: *The High Frontier*, Anchor Press Doubleday, New York, 1982, and *2081: A Hopeful View of the Human Future*, Simon & Schuster, New York, 1981. ◆

Illustration sources

Opening illustrations for the four sections of this issue are: [1] Crossroads in space—R2-D2 watching the approach of the uncharted planet, Dagobah, from his cubbyhole on the back of Luke Skywalker's X-wing fighter in *The Empire Strikes Back*. Courtesy Lucasfilm Ltd.; [2] Space technology—A 3-inch VLSI wafer manufactured by Comsat General Integrated Systems, superimposed on a blowup of one of its circuit elements. Courtesy William J. Megna/Comsat; [3] The politics of space—A NASA artist's depiction of the planned International Solar Polar Mission; and [4] The future of space—The Galileo orbiter releasing its atmospheric probe designed to make the first measurements of Jupiter's atmosphere, in a NASA artist's conception of a planned 1986 mission.

ABOUT THE AUTHORS

James M. Beggs is the administrator of the U.S. National Aeronautics and Space Administration. Prior to the middle of 1981, he was the executive vice president and a director of General Dynamics Corp. in St. Louis, Mo., which he joined in 1974. Dr. Beggs previously worked for NASA from 1968 to 1969 as associate administrator of the Office of Advanced Research and Technology.

Robert W. Buchheim is a consultant to the U.S. Arms Control and Disarmament Agency. He was the manager of the U.S. delegation negotiating the Treaty on Peaceful Nuclear Explosions and chairman of the interagency study group leading to the U.S.-USSR initiative on a convention on radiological weapons. During President Jimmy Carter's administration, Ambassador Buchheim led the U.S. delegation at the antisatellite (ASAT) talks with the Soviet Union. He has also been the U.S. commissioner on the U.S.-USSR Standing Consultative Commission, which considers complaints of one country against the other.

Hubert Curien is the president of the Centre National d'Etudes Spatiales (CNES), the French equivalent of NASA. He is also the chairman of two international associations: the Council of the European Space Agency, in Paris, which associates 11 European countries for the development and building of launchers and satellites, and the European Science Foundation, in Strasbourg, France, which is a federal group set up through the consensus of 40 research centers located in 16 European countries. Dr. Curien is a full professor at the University of Paris where his research addresses the study of soiid matter.

Robert A. Frosch (F), vice president in charge of the General Motors Corp.'s Research Laboratories in Warren, Mich., heads a science team engaged in applied research and development, long-range research, and specialized-service work for other GM units. For three and a half years, he was a NASA administrator, after which he became president of the American Association of Engineering Societies, the engineering society umbrella organization.

Arnold W. Frutkin, currently assistant to the president of the International Group of Burroughs Corp. in Detroit, Mich., headed NASA's international-relations office for almost 20 years. From 1977 to 1979 he served as the associate administrator of external affairs for NASA and from 1959 to 1977 as assistant administrator of international affairs. From 1962 to 1976, he served intermittently as U.S. Representative to the United Nations Committee on Outer Space Affairs.

John H. Glenn Jr. was elected to the U.S. Senate in 1974 and reelected in 1980. He serves as a member of the Foreign Relations Committee, Governmental Affairs Committee, Special Committee on Aging, and the Senate Democratic Policy Committee. Mr. Glenn, in the initial group of seven men chosen to be astronauts, became the first U.S. citizen to orbit the earth on Feb. 20, 1962, in the Mercury-Atlas 6 "Friendship 7," and assisted in the design and development of Project Apollo.

S. Neil Hosenball has been NASA's general counsel since 1975 and was deputy general counsel from 1967 to 1975. Earlier he was assistant general counsel for procurement matters and worked for four years at the NASA Lewis Research Center in Cleveland, Ohio, as its chief counsel. From 1970 to 1979, Mr. Hosenball was a member of the U.S. delegation to the United Nations Committee on the Peaceful Uses of Outer Space.

George A. Keyworth II was appointed the director of the Office of Science and Technology Policy in the Executive Office of the President in 1981, where he is science advisor to the President. Specializing in nuclear physics, Dr. Keyworth previously was head of the experimental physics division at Los Alamos, N.M., which consisted of several hundred scientists and technicians whose work encompassed basic research in nuclear and fundamental interactions, condensed matter research, astrophysics, space sciences, and applied research toward satellite-based verification of compliance with nuclear test treaties and the physics of superhigh-energy densities.

John M. Logsdon has occupied the space history chair at the National Air and Space Museum of the Smithsonian Institution for the past year. In the fall, he will return to George Washington University in Washington, D.C., where he is director of the Graduate Program in Science, Technology, and Public Policy and professor of political science and public affairs. His research interests include space policy, the structure and process of government decision making for research and development programs, and international science and technology policy. An active member of the American Institute for Aeronautics and Astronautics, Dr. Logsdon has been a consultant to the United Nations, the National Science Foundation, Department of Commerce, Office of Technology Assessment, Environmental Protection Agency, Intelsat, and other public and private organizations.

Theodore R. Simpson (SM) has more than 22 years of experience in the aerospace industry, having worked in the U.S. space program and the air-traffic control system. Currently, he is the project leader at ANSER (analytical services), a consulting firm, where he is doing long-range planning for the U.S. Air Force space program. He contributed to the development of the U.S. Air Force Space Plan and at the present time he is helping to define the military uses for a space station. During 1981, he was an IEEE Congressional Fellow and served on the staff of the Senate Subcommittee on Science, Technology, and Space, where his responsibilities included covering the civilian space program for the subcommittee.

Acknowledgements

The broad range of this special issue and its long time in gestation meant that *Spectrum* editors called on more than 200 experts for advice and counsel. Some became authors, many became sources, still others became reviewers, and no small number labored valiantly to be all three. The list below attempts to thank some of the people without whom we could not have produced this issue. But the issue editor wishes first to make special mention of one of them, David Williamson, who played a very special role in pointing us in the right direction at every step as we put the issue together. Among the others (excluding expert authors listed above) were Tony Calio, Ralph Chipman, Sajjad Durrani, Freeman Dyson, Burton Edelson, Derrick Elliott, Jerry Grey, Paul Hanle, James Hartinger, Richard Henry, Noel Hinners, Martin Horwit, Diana Hoyt, George Low, Hans Mark, John McLucas, Ahmed Meer, Wilfred Mellors, James Morrisson, Bruce Murray, Thomas Paine, Jesco von Puttkamer, Simon Ramo, Eberhard Rechtin, Victor Reis, Harold Rosen, Alex Rowland, Irwin Shapiro, Paul Slee, Willis Shapley, Marcia Smith, Norman Terrell, John Townsend, Len Weiss, Walt Williams, Ray Williamson, and Monte Wright.

Included in this listing are experts who reviewed one or more articles and have given us permission to identify them. Their listing does not mean they necessarily endorse any given viewpoint expressed.

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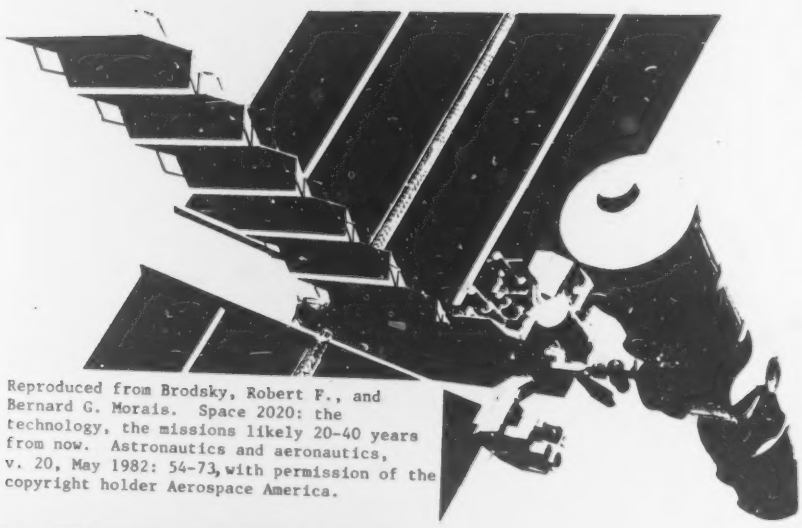

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SPACE 2020

THE TECHNOLOGY, THE MISSIONS LIKELY 20-40 YEARS FROM NOW

By ROBERT F. BRODSKY
TRW Space and Technology Group

and BERNARD G. MORAIS
Lockheed Missiles & Space

▲Power System Platform from TRW could have two Spacelab modules to house a crew of four for 90 days between resupply

In two decades space activities have become an accepted and integral part of the lives of a large fraction of the Earth's people and vitally affect the remainder. No one could predict in 1960 the twenty years in space that have just passed, and it is impossible to predict the next twenty. Since those years will determine what happens thereafter, the years 2000 to 2020 are certainly beyond present conception. This report does not attempt to predict what will happen in space, but helped by the insight of almost fifty space-dedicated professionals selected for both their technical expertise and breadth of viewpoint, it sets out what could happen.

Technology 20-40 years from now (T-1) will give us spacecraft electrical plants supplying up to 3000 kw, space structures as long as 400 m on a side, positioning to within 1 m in orbit, communications at rates above 10^3 Mbits/sec, and systems able to operate untended for up to 20 years—30 years perhaps in the case of proto-colonies.

Considerable planning has already been done by government agencies and others for the period leading up to the decades of interest. Many of the programs projected for this period have been approved, and progress for the most part will likely be evolutionary and in accordance with present trends.

U.S. domestic communication satellite capacity is equivalent to 150 36-MHz transponders (or 150

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color TV channels). This represents approximately 672 voice channels. Traffic is projected to need over 800 channels by the mid-1990s (F-1), when satellites will carry approximately 13% of domestic communications. The introduction of high frequency (30/20 GHz) technology would permit increasing capacity to 2352 channels or about 25% of projected communication requirements in 2000.

Frequency reuse techniques would further increase possible satellite capacity to over 4000 channels by 2020. This capacity roughly matches both projected satellite communication requirements and overall domestic communication requirements. These developments will avoid overcrowding the geosynchronous orbit, where the number of spacecraft has grown consistently at 24% per year.

After the Space Shuttle and its early growth versions, attention will probably focus on Shuttle-derived launch vehicles. New orbital transfer vehicles (OTV) will be needed in the 1990s.

Large space system missions using these launchers in 1980-2000 may include many new commercial and government space applications (T-2, F-2).

A considerable number of technically low-risk missions could be carried out in this period (T-3). Some higher-risk applications may be exploited if needs are strong enough. Most of the riskier missions will for the most part remain in development into the next century.

The basic physical research programs and experiments conducted in near-Earth space from 1981 to 1999 will take advantage of nearly zero gravity (10^{-5} to 10^{-6}g), pressures below any Earth laboratory vacuum, and the absence or reduction of terrestrial disturbances produced by such sources as the atmosphere, ionosphere, Earth vibrations, or radio signals. Representative experiments of basic importance using these and other orbital properties include zero-gravity fluid dynamics, plasma physics, and relativistic clock experiments.

Much more astronomy and astrophysics research in space will evolve from the Space Telescope, Space Infrared Telescope Facility, solar optical and ultraviolet telescopes, spectrographs and coronagraphs, and X-ray and gamma-ray detectors to be carried on or launched by the Shuttle beginning in the 1980s. By the 1990s, an optical telescope of 3-4-m aperture is expected to be tended by man visiting from a nearby low-Earth-orbit (LEO) base.

Solar system exploration in the 1980s and 1990s (F-3) after the approved 1984 Galileo Jupiter orbiter and probe may slowly expand to include:

- Mercury orbiter, about 1989; Mercury lander, about 1993.

Man will have begun to exploit the solar system and will be poised to explore the galaxy beyond it

- Venus orbiting imaging radar, 1986-88; Venus soft lander, 1988-1990.
- Mars surface rover, mid-1990s.
- Saturn orbiter and probe, about 1988.
- Neptune flyby (Jupiter gravity assist), late 1980s.
- Landers on Titan and one or more of the Galilean satellites of Jupiter, such as Ganymede, mid- to late 1990s.
- Lunar orbiter, mid-1990s (primarily to update lunar characteristics in preparation for a manned landing in 2000 to 2005).
- Halley's Comet fast flyby, 1985; comet rendezvous, 1988 to 1990.
- Asteroid flyby, early 1990s.

If Galileo is cancelled, the above missions may be delayed or dropped.

NASA has drawn up unapproved plans for exploring the solar system between now and the end of the century. The plans sketched above map a fairly slow, but steady pace of unmanned missions over the next two decades, which will include detailed investigations of comets, imaging radar mapping of Venus, solar missions, detailed investigations of the Jupiter and Saturn systems, and finally a detailed geochemical/geophysical mapping of Mars, followed by the return of samples from Mars near the turn of the century.

The timing for a Saturn mission coincides with a series of Jupiter swingby opportunities to Uranus, Neptune and Pluto. A decision might be made to take advantage of the opportunity to complete our reconnaissance of the solar system and to delay the detailed Saturn investigation.

Notably absent from present NASA planning is a return to the Moon's surface, although a joint mission with the European Space Agency to perform geochemical and geophysical mapping of the Moon from orbit is a good possibility. In any case, a lunar orbiter should be flown in the late 1990s in preparation for manned lunar activity in the first decade of the new century.

The official plan should probably be viewed as middle of the road. Fiscal restrictions may kill the relatively ambitious missions in it. Reconnaissance missions to Earth-approaching asteroids or inner

T-1 SPACE TECHNOLOGIES IN 2000-2020 FOR TYPICAL MISSIONS AND CAPABILITIES

Technologies—key parameters	Communications	Earth observations	Manufacturing, incl. space processing	Nuclear waste disposal	Lunar exploitation	Proto-colonies	Space science, incl. astrophysics	Solar system exploration	Military missions	Space transportation	Space stations and operations	Space construction
Materials—A. high temp. metals, B. composites, C. ceramics	B	B	A,B,C	B	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C	A,B,C
Propulsion—Effective jet vel., km/s	~20	~20	~20	4	4-40	—	~20	3-100	3-100	3-100	~20	~20
—Thrust accel., m/n	low	0.01	low	10^{-3}	10^{-3}	low	10^{-3}	10^{-3}	10^{-4}	10^{-3}	10^{-3}	10^{-3}
Power—Level, kw_e	25	25	1000	10	1000	500	20	3000	3000	3000	500	250
—Spec. system mass, kg/kw_e	10	30	10	10	10	10	30	10	15	10	10	10
Structure—Scale dimension, m	10^3	400	10^3	100	10^3	10^3	50	100	100	100	200	10^3
Navigation, guidance & control												
—Position, m	100	10	10^3	10^4	10^3	10^3	10^3	10^3	1	1	10^3	10^3
—Pointing: coarse/fine/articulated, deg	0.1	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.01	1.0	1.0
	0.01	0.01	1.0	0.1	0.1	1.0	0.1	1.0	0.1	0.01	0.1	0.1
	0.01	0.0001	0.1	0.1	0.01	0.01	0.001	0.01	0.0001	NA	0.001	0.1
Communications—Bit rate, Mbits/s	7	10^3	500	—	500	100	10	10	10^3	10	100	100
Command & data handling												
—Ops. rate, ops./s	10^8	10^8	10^8	10^8	10^8	10^8	$1\ 0^6$	10^6	10^8	10^6	10^8	10^8
—Storage, Mbits	—	10^{15}	10^{10}	—	10^{15}	10^{15}	10^{10}	10^{12}	10^{12}	10^{10}	10^{15}	10^{10}
Autonomy—Untended systems duration, yr	>10	>5	7	1	0.2	~30	>5	>10	~7	~1	20	10

main-belt asteroids may then survive along with missions to both the inner and outer planets substantially reduced in scope. Such missions may carry one or two experiments rather than the broad multidiscipline investigations now envisioned.

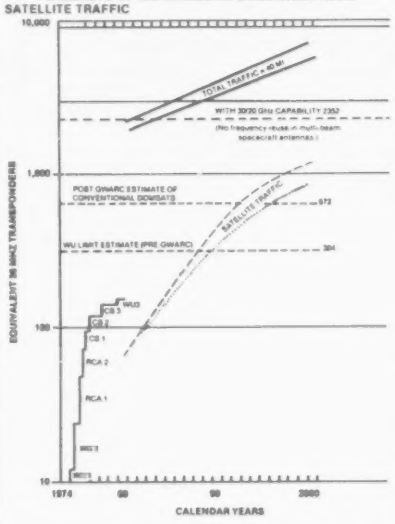
In general, the goals discussed could be reached with current or near-future technology. Development of high-energy propulsion technology would help. Electric propulsion, which has application to asteroid and comet missions, Mercury orbiter, and some outer planet missions, would be nuclear-powered rather than solar. Solar sailing may be used in some missions. Planetary exploration will exploit the ability of astronauts on the Shuttle to add an Inertial Upper Stage (IUS) or a more powerful OTV to a spacecraft already in Earth orbit. Atmospheric braking at the planets will conserve propulsion fuel.

Once the Space Transportation System (STS) becomes operational, full attention must be given to space stations. The Soviets have mounted a clear and substantial challenge, although they still depend on expendable launchers. Attention in the U.S. seems to be turning to an early permanently manned facility in low Earth orbit and a later one in geostationary orbit.

A NASA conceptual program plan leading toward the development and understanding of large space structures (F-4) makes full use of the Shuttle in deploying and constructing typical large structures such as antennas and platforms.

Military space vehicles for observation, communication, and navigation will probably improve at the present rate during the next twenty years, and some

F-1 FORECASTS OF U.S. DOMESTIC COMMUNICATIONS SATELLITE TRAFFIC



new space weapons may appear. Space defense and operations will surely be very active but depend much less on technology than on world politics for their impetus.

Military spacecraft are expected to ride the Shuttle into LEO on the way to their eventual orbits and sometimes to sortie from the Shuttle.

HOW THIS REPORT CAME ABOUT

In the summer of 1980, at President Carter's request, the National Academy of Sciences formed a special committee to study the feasibility of the Solar Power Satellite (SPS). The committee requested the AIAA to set the stage quickly for them by visualizing the state of space technology in 2000-2020 if the SPS were not undertaken. Then AIAA President Artur Mager asked then Space Systems TC Chairman Richard Kline of Grumman Aerospace to organize his committee to reply to the request. This effort was started by an ad hoc subcommittee in August 1980 under the direction of consultant J. Preston Layton.

A 170-page document, dated January 14, 1981, and titled, "Projected Space Technologies, Missions and Capabilities in the 2000-2020 Time Period," resulted. This condensation by two members of the TC attempts to extract the "meat" from the report without losing too much of the flavor.

Contributors

Ad Hoc Subcommittee: Layton; Jerry Grey, AIAA Administrator, Public Policy; Ivan Bekey, NASA Headquarters; James R. Blankenship, RCA Astro-Electronics; Kevin C. Daly, Charles Stark Draper Laboratory; Hubert Davis, Eagle Engineering; M. Edmund Ellion, Hughes Aircraft; Jerry J. Florey, Rockwell International Space Div.; W. Ray Hook, NASA Langley Research Center; Kline; Peter T. Lyman, Jet Propulsion Laboratory; David J. Rohrbauch, Boeing Aerospace; Maj. Stanley G. Rosen, Office of the Secretary of the Air Force, Special Projects; Fred Terren, NASA Lewis Research Center; Wilfred J. Mellors, European Space Agency; Denis J. Curtin, Comsat General; Dale A. Fester, Martin Marietta; and Joseph Garibotti, McDonnell Douglas. *Other contributors:* Larry B. Bassham and Rudi Beichel, Aerojet Liquid Rocket Co.; John Mosich, Malcolm G. Wolfe, Robert A. Davis, and W.P. Thompson, the Aerospace Corp.; Vincent Calouri and Eldon E. Davis, Boeing Aerospace; Joel Greenberg, Econ, Inc.; James R. Burke, Phillip W. Garrison, Alex Goetz, Jeffrey Leising, Edward Posner, and Marc Raibert, Jet Propulsion Laboratory; Robert A. Fuhrman and Rudi Buschmann, Lockheed Missiles & Space; Ralph Eberhardt, Martin Marietta; Richard Carlisle and E.A. Gabris, NASA Office of Aeronautics and Space Technology; James J. Jones, NASA Langley Research Center; Raymond Miller, Arthur Nussberger, Richard Long and Ronald Ogelvie, Rockwell International; Gerard K. O'Neill, Joel A. Kubby, and R. Scott Dunbar, Space Science Institute; and Robert Salkeld, System Development Corp.

Many of the missions chosen to exploit the numerous military opportunities of the next twenty years (T-4) will clearly carry over into 2000-2020.

Where there is both military and civilian interest, as in ocean monitoring, meteorology, navigation and positioning, and air-traffic control, major programs are expected to be run increasingly as joint ventures to the end of the century and beyond.

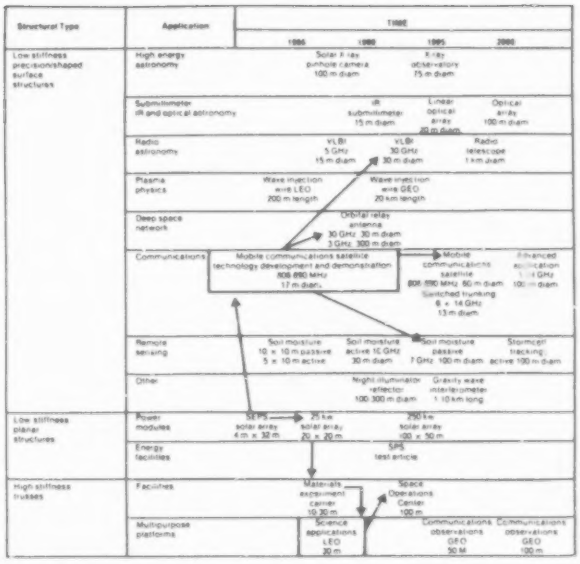
Cooperative international programs will grow more common as other nations strengthen their space programs, the ranks of the spacefaring nations swell, and missions become more sophisticated. Missions extending over decades will cost more than one business organization or nation can pay. The variety of talents and skills called for will also argue for international teams.

In recent years in the United States, too little funding has been available for space research and technology development to maintain leadership. Moreover, much of the work has been focused on limited, short-term objectives. Although the wastefulness of unfocused research and unrestricted and premature technology development cannot be denied, the constraints and stingy funding of the past decade may have dangerous consequences. Funding to build the research and technology bases should be strengthened well beyond that presently planned, or the technology available at the start of the 21st Century will be inadequate. This is particularly true for materials for space application.

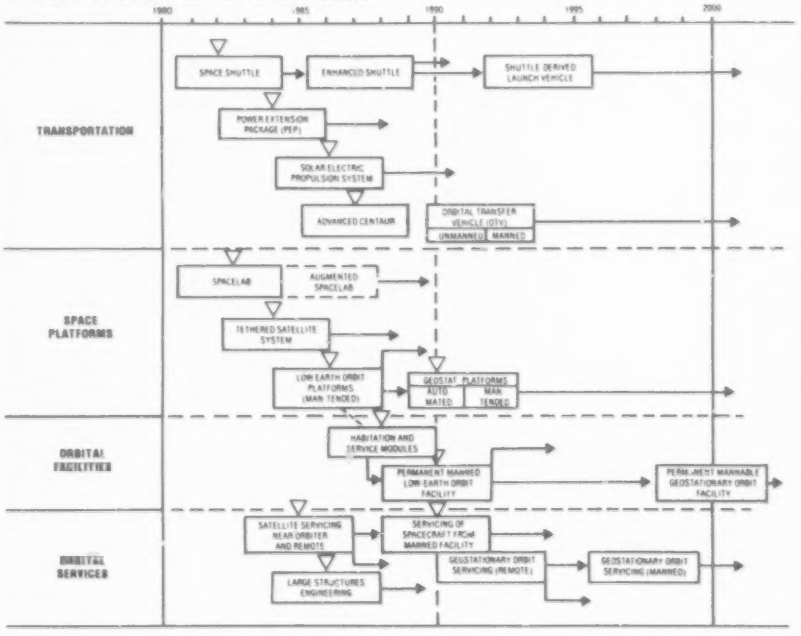
Determining physical, chemical, and electrical properties, product availability and cost, fabrication characteristics with similar and dissimilar materials, and the effects of aging takes a long time. Work on new materials for the year 2000 must be started very soon. Although some efforts are in progress, much broader and more thorough programs are needed.

ROBERT F. BRODSKY (AF), at left, is a senior systems engineer for TRW Space & Technology Group working on advanced spacecraft and space platforms. From 1971 to 1979 he headed Iowa State University's Aerospace Engineering Dept. Brodsky chaired the Aerospace Dept. Chairmen's Association, and both the AeroSpace Div. and the Technology Assessment Committee of the American Society for Engineering Education. He holds a BSME from Cornell Univ., an MS in aeronautics from NYU, a Master's in applied mathematics from the Univ. of New Mexico, and a Doctorate in engineering from NYU. **BERNARD G. MORAIS** (M) directs system engineering for the Space Systems Div. of Lockheed Missiles & Space. In 21 years at Lockheed he has worked on the Standard Agena, Ascent Agena, a number of launch vehicle programs using the Agenas to launch USAF spacecraft, and an Air Force orbiting vehicle. He chairs the 1982 AIAA/NSIA/USAF Space Div. Military Space Systems Technology Workshop. Morais received a BSEE in 1959 from California State Polytechnic-San Luis Obispo, and an MS in systems management in 1974 from the Univ. of Southern California.

T-2 POTENTIAL MISSIONS FOR LARGE SPACE SYSTEMS
From AAS Paper 80-275.


Structural Type
Application
Time
1985
1990
1995
2000
Low stiffness precision/shaped surface structures
High energy astronomy
Solar X-ray pinhole camera 100 m diam
X-ray observatory 15 m diam
Submillimeter IR and optical astronomy
IR submillimeter 15 m diam
Linear optical array 20 m diam
Optical array 100 m diam
Radio astronomy
VLBI 5 GHz 15 m diam
VLBI 30 GHz 30 m diam
Radio telescope 1 km diam
Plasma physics
Wave injection w/ns LEO 200 m length
Wave injection w/ns GEO 20 km length
Deep space network
Orbital relay antenna 30 GHz 30 m diam 3 GHz 300 m diam
Communications
Mobile communications satellite technology development and demonstration 806-890 MHz 17 m diam
Mobile communications satellite 806-890 MHz 80 m diam
Switched trunking 6 + 14 GHz 15 m diam
Advanced application 1-14 GHz 100 m diam
Remote sensing
Soil moisture 10 x 10 m passive 5 x 10 m active
Soil moisture active 1C GHz 30 m diam
Soil moisture passive 7 GHz 100 m diam
Stormcell tracking active 100 m diam
Other
Night illuminator reflector 100-300 m diam
Gravity wave interferometer 1-10 km long
Low stiffness planar structures
Power modules
SEPS solar array 4 m x 32 m
25 kw solar array 20 x 20 m
250 kw solar array 100 x 50 m
Energy facilities
SPS test article
High stiffness trusses
Facilities
Materials experiment carrier 10-30 m
Space Operations Center 100 m
Multipurpose platforms
Science applications LEO 20 m
Communications observations GEO 50 M
Communications observations GEO 100 m

F-2 GROWTH OF CAPABILITIES IN EARTH ORBIT 1980-2000



T-3 SPACE APPLICATIONS AND THEIR RISK ESTIMATES FOR THE 1980s AND 1990s
Risk increases with number.

Commercial	Risk category	Government	Risk category
Personal		**Communications**	
Personal communications wrist radio	I	Voting/polling wrist set	I
Emergency/rescue wrist beacon	I	Electronic mail transmission	I
Personal navigation wrist set	II	Border surveillance	II
Voting/polling wrist set	I	Nuclear materials locator	I
Civic		Library data sharing	I
Disaster communications wrist radio	I	**Observation**	
All-aircraft traffic control	I	High resolution resources/pollution observatory	II
Urban/police wrist radio	I	Water level and fault movement indicator	I
Car speed-limit control	I	Atmospheric temperature profile sounder	III
Industrial		Forest fire detection	I
Burglar alarm intrusion detection	II	Ocean resources location	I
Vehicle/package locator	II	**Support**	
3D holographic teleconferencing	III	Passive coastal anti-collision radar	II
Advanced TV broadcast	I	Night illuminator	II
Advanced resources pollution observation	I	Energy delivery and distribution	IV
Space processing	I/II	Energy consumption monitor	I
International		Aircraft laser beam powering	IV
Nation-nation "hot lines"	I	Nuclear waste disposal	II
Multinational air traffic control radar		**International**	
Small terminal Intelsat network	I	Astronomical super-telescope	IV
Earth resources data sharing	I	Interplanetary TV link	II
Energy distribution relay	IV	Atmospheric temperature profile sounder	III
UN truce observation satellite	I	Ocean resources and dynamic sensor	I
		Water level and fault movement indicator	I

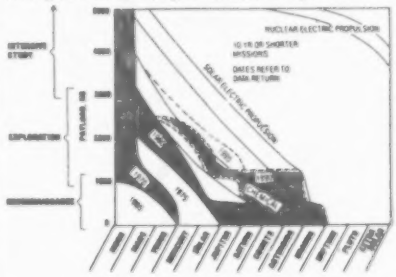
Materials for use in space must be adequately characterized and their production and fabrication techniques must be established, since testing devices under operational conditions for extended lifetimes is very difficult.

Materials should also be screened to find those most likely to be improved by processing in space, and early efforts should be made to develop special characteristics by working them in the extremely low gravity and high vacuum of space. Materials properties quite different from those we are familiar with may result from such research.

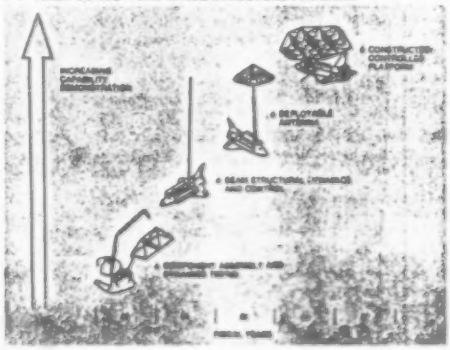
By the year 2000 large structures such as permanently-manned space stations may be in geosynchronous orbit and space factories and housing for space workers may be on the immediate horizon. Placing all that material in orbit from Earth will be expensive. An alternate source of raw materials is the Moon. Processing lunar materials in the vacuum of space will permit using for structures many elements that are not suitable on Earth. For example, the alkali metals can be used as both structural and electrical materials. Sodium has excellent specific electrical conductance. In space the number of materials that can be used directly will more than double, and the number of applicable alloys will increase geometrically. Some of these materials, when properly alloyed, might also prove suitable for use on Earth.

New and more advanced composites will be lighter, stronger, more dimensionally stable, stiffer, have higher temperature resistance, and last longer when used in space. They will be composed of

F-3 SOLAR SYSTEM EXPLORATION MISSIONS
For single Shuttle launch, flight times less than 10 yr.



F-4 NASA CONCEPTUAL SPACE STRUCTURE PROGRAM



T-4 MILITARY OPPORTUNITIES, FEATURES, RELEVANCE, AND KEY TECHNOLOGIES
From Stanley Rosen.

Opportunity (operational time period)	Features	Relevance	Key technologies
Global info/C^3 network (early 70s)	All-source 10^2-10^3 Mbps data trunks Hi/lo data rate tap-off by users on demand Redundant sat-sat links, auto-reconfiguration Smart terminals	Moderate-to-high conflict levels Follow-ons to DSP/SED DSCS III, GPS III, SCF RTS ZI control of theater RPVs Data fusion centers NASA TDRSS, needs Sat. business system Remote sensing system data distribution	On-board data processing Sat-sat links, e.g. laser, V-band Mil spec VHSIC/rapid access memories Terminal design/human interface IR and radar sensors
Advanced military space transportation (mid-late '90s)	Manned/fully reusable Demand missions Fast response (hrs) Low cost, small fleet (~5) Force exercise Basing flexibility High survivability	Moderate-to-high conflict levels All missions NASA Shuttle upgrade and followon reqs. Commercial shuttle	Chem propulsion eff. jet vel. = 4560 m/s Composite materials, adv. structures inert fraction ~0.10
On-orbit operations (evolving beginning in early '80s)	Checkout and deploy Inspect, repair, upgrade, refurbish, activate, retire, retrieve Make and process Test and experiment Conduct sortie missions Rescue	Low conflict levels Development, design acquisition of DOD space systems Large structures in space Space defense monitoring and damage assessment Commercialization of space Space test program Standardization Space debris control	Crew training, endurance and survivability Mission assist— —Teleoperators —Micro processors —Client design for servicing —Tumbelsat capture —Retrieval rocket packs
Large space structure systems (mid-late '90s)	30-300 m diam. antennas	Moderate-to-high conflict levels Battlefield sensor R/O—20 m, kw_e RPV control—60 m, 100 kw_e Trooper comm.—75 m, 100 kw_e Battlefield illum.—300 m, 2 kw_e Jammer—600 m, 300 kw_e Multistatic radar—335 m, 500 kw_e Civilian large space structures	Construction in space Attitude and figure control High power supplies— —Nuc. reactor > 20 kw_e Survivability
High physical survivability (continuing)	Backup payloads— —Spares on orbit —Demand launch Autonomy from ground stations Keep-out zone monitoring Debris control	All conflict levels All missions On-orbit operations Advanced military space transportation Launcher options/SALT	Autonomous space navigation/fault tolerant SP comp. Emergency satellite design Maneuvering Dsat weapons

metal, organic (such as high-temperature polyamides), ceramic and glass matrices and fibers made of organics such as aramids, inorganic non-metals such as graphite, ceramics, and glasses, and metal wires, whiskers, and ribbons.

Materials shipped from Earth to be converted into various structures will be packaged more efficiently. For example, sodium may be used to make electrical conductors. If it were shipped as a hydroxide, it could be disassociated in space into sodium metal, oxygen, and water, all of which would be useful.

Ceramics are receiving attention for aerospace applications because they are well characterized under substantial stress at high temperature. They will find much greater use in devices such as closed Brayton cycle space power systems where temperatures above 1100 K are desired (F-5).

Other materials used in space will include specially tailored plastics and special forms of rare elements and nuclides. Programs for projecting requirements for special materials and testing their properties in space under realistic operating conditions are needed soon to lay a proper foundation for space activities after the turn of the century.

Space structures in 2000-2020 should fall into two distinct categories: pressure vessels and open frames. Pressure vessels are relatively "dense" structures, robust and able to stand some handling abuse. Open frames are generally large and fairly delicate.

Pressure vessels are used for fluid storage, habitation and laboratory modules, and space workshops. They will come in a wide range of sizes. Most will fit within the Orbiter cargo bay (4.5 m diam. × 18 m long). Limited use may be made of specially adapted versions of the Shuttle External Tank (8 m diam. × 47 m long). Giving the empty

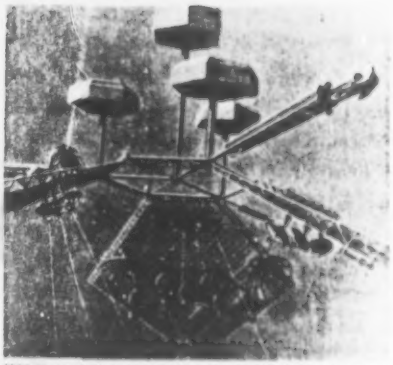
tank a small amount of extra velocity can boost it into a low Earth orbit. There it could serve as a workshop, a large-volume fluid store, or a relatively rigid workbench with a large external area for construction, assembly, or experiments.

Open frame structures are typically used for large antennas and for extended platforms. Antennas for frequencies up to 1000 GHz and with a longest dimension up to 10 km will, for the most part, be fabricated on the ground and unfolded in space. This will hold for all antenna types—reflectors, phased arrays, or hybrids. Antennas will reach 300 m diam. by the year 2000, and 1 km diam. by 2020. They will use composites for compression members and tension trusses to minimize thermal distortion.

Platforms will use three lightweight space framework approaches: ground fabricate/space unfold, ground fabricate/space assemble, and space fabricate/space assemble.

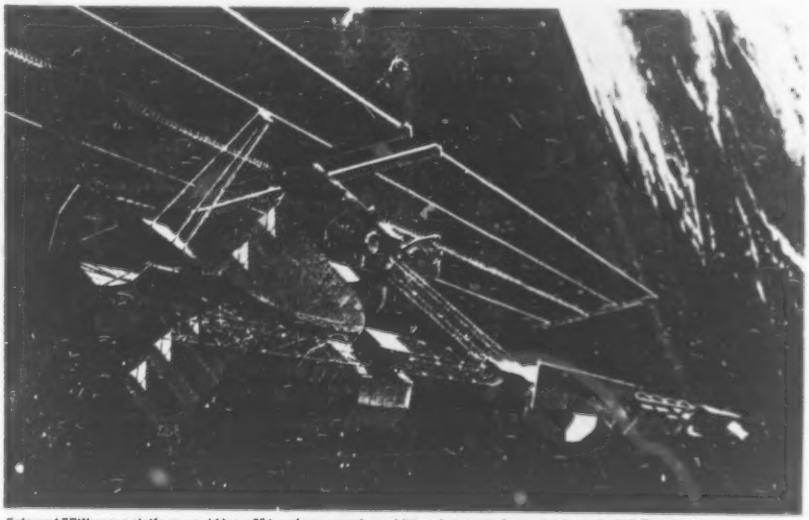
The third method will come into play for only the largest platforms.

A typical platform in the year 2000 will have an area of about 100 m^2 with structural members mostly 5-15 m long. By the year 2020, platforms of 10,000 m^2 will be needed. These could be either ground fabricated/space assembled or space fabricated/space assembled. They will be made of both aluminum and composites.



Military or civilian space station for 2000-2010 from Lockheed would have lasers as either weapons or communications carriers (antenna-like structures with beams). Each of three vehicle docks can accommodate three craft at a time. Central pentagonal structure at top houses control and power equipment and some crew. New segments can be added down the column. Outlying pentagons serve as work stations, have solar cells as a standby independent source of power. All pentagons can be spun to create artificial g. Large bubbles at bottom are OTV hangars. Small ones and tanks at right store propellant. Domes on left gridwork are observatories. Grid is 10 m thick.

Space construction bases will use robots to locate, translate, and rotate large, lightweight thin-sectioned structures, and apply quality control and joint-integrity verification methods, in-space repair methods, and space fabrication machines now called beam builders. Beam builders under development make both aluminum and composite members in sizes that may well satisfy the needs of 2000-2020.



Enlarged TRW space platform would have 25 kw of power and an additional structure for payloads such as VLBI radio telescope.

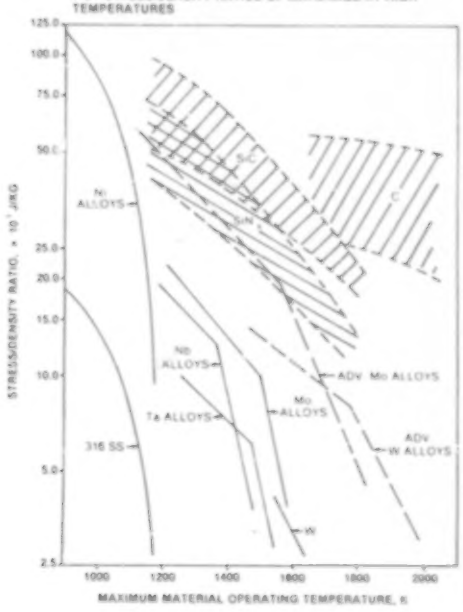
Their use may not be routine by 2000, but will be by 2020.

In space, as in aircraft technology, propulsion advances make things happen. Well before the end of the century, the STS engines will be outmoded and have to be replaced.

By 2000 the IUS and spinning solid upper stages will probably have been replaced by versatile liquid propellant upper stages and by an early version OTV, probably with an improved RL-10 liquid oxygen/liquid hydrogen engine. An advanced OTV, with increased payload and other capabilities, and possibly based on a small space platform, will have been built. Studies and analyses to define the OTV missions and traffic should begin now, in conjunction with space station studies.

Large booster and launch vehicle first stage engines with high density hydrocarbon fuels will be needed around the turn of the century or sooner for Shuttle growth and derivative versions. They will be followed by advanced-technology dual-expander engines using both hydrogen and liquid oxygen as coolants. These engines will be designed primarily for single-stage-to-orbit and heavy-lift vehicles.

F-5 STRESS/DENSITY RATIOS OF MATERIALS AT HIGH TEMPERATURES



Solid rockets burning high energy and hybrid propellants will continue to be developed for special applications, but will be largely replaced by liquid rockets in all but launch boost applications.

Advanced electric propulsion will have been demonstrated on experimental flights and unsophisticated operational missions by 2000. It will have the technology of the present or slightly improved solar/electric propulsion system.

By the early 21st Century the present ion bombardment thrusters will have increased in size from 30 cm to 50 or 120 cm diameter. For many, especially near-Earth, applications mercury propellant will probably be replaced by noble gases or other easily ionizable materials.

Magnetoplasmadynamic (MPD) thrusters are just emerging from the research laboratory, but should be ready for application in 2000-2020. Pulsed and steady-state MPD propulsion promise greater efficiency and simplicity than ion propulsion of higher thrust density without the necessity for neutralizing the exhaust stream.

Other methods of propulsion that may be developed in 2000-2020 include solar sailing, laser propulsion, fusion micro-explosion rockets, and mass driver reaction engines. One interesting concept with great technical challenge and mission potential that is being considered is a matter-antimatter annihilation rocket engine. Means for generating and handling the anti-proton working fluid and other aspects have been studied on paper.

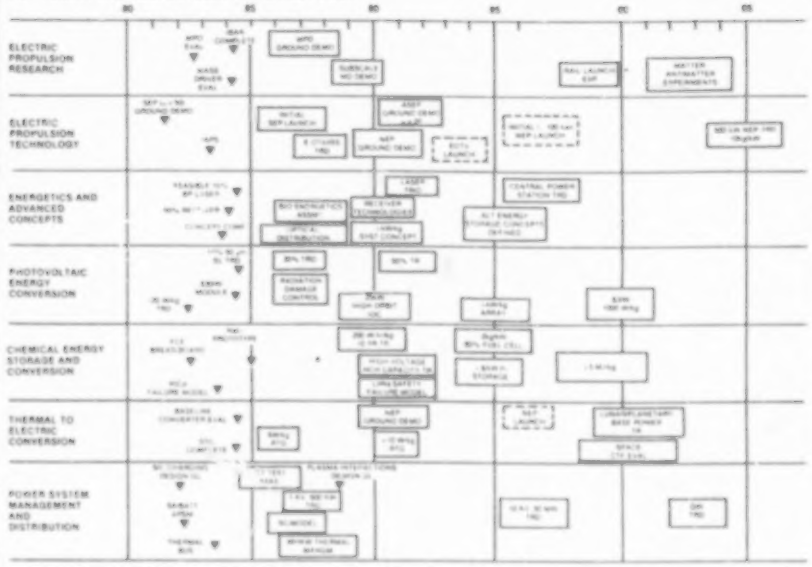
Insufficient electric power has limited the performance of spacecraft. New power systems in the next twenty-five years should remove this restraint (F-6). Many of the items shown in F-6 may be delayed until after the turn of the century, especially nuclear systems and those for higher power.

Research and technology in aerothermodynamics will be directed toward advanced space transportation, planetary exploration, and atmospheric maneuvering vehicles. Technology areas receiving emphasis are flow field computational methods, heat shield materials, and rarefied flow analyses. Certain viscous interaction regimes such as shock-induced boundary layer separation and transition to turbulent flow will continue to receive attention.

Each of the above technologies should have matured by 2000 into practical engineering tools based on sound understanding of their physics, and new topics we cannot predict will have replaced them as subjects of research by 2020.

Active electronic systems will replace passive approaches to structural, altitude, and thermal control to satisfy demands for increased efficiency and performance. Integrating electronics into all critical

F-8 TWENTY-FIVE YEAR OUTLOOK FOR SPACE POWER



components of space systems will call for significantly different design approaches, as we try to make spacecraft completely self-repairing.

All electronic systems in critical applications will have high fault tolerance and adaptability. Loss of function due to random failure or damage will not be accepted. Equipment will incorporate autonomous failure detection, identification, and reconfiguration, and redundant portions that can be called on to permit long-term operation. The electronic systems will be able to adapt to a wide range of changing environments such as those encountered during the construction of a large platform.

Purely electronic systems will dominate sensor technology 2000-2020. Mechanical scanning will be replaced by high density focal plane arrays in the spectra from untraviolet through infrared. Radio frequency (RF) sensors will become increasingly important for Earth observation. Multispectral systems will be based on tunable detectors, some using optical heterodyning. Active optics will give figure control and aperture shaping allowing wide freedom in trading resolution for power (noise). Apertures of hundreds of meters will be used at RF, and figure control will maintain aperture surfaces accurate to within 1/50 of a wavelength or better.

Line-of-sight pointing control will be to submicroradian accuracies for some antennas below 1000 km and for most antennas at synchronous altitude and above. IR and RF sensors will have both active and passive coolers. Passive sensors on a satellite will consume 5-10 kw, and active sensors, 25-50 kw.

Satellites will have large numbers of sensors collecting data at the rate of megabits per second. To keep storage and transmission within reasonable bounds, the satellite will need enough processing capacity to compress sensor output and still extract vital information. Contrary to practice in the '80s, much information gathered by satellites in 2000-2020 will be used in real time on the ground.

Satellites will navigate themselves rather than being tracked and controlled from the ground. They will determine their positions in real time and use that information for control, coordination with other satellites, and processing sensor data. Navigation measurements will be made from astronomical bodies and from groups of satellites positioned for that purpose that will also serve for navigating at sea, on land, and in the air. Spacecraft will locate

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themselves within 1 m or less, and, when rendezvousing or docking, will determine relative positions to an accuracy of 1 cm.

All spacecraft will exercise active control of attitude and configuration to maintain electronic and optical structural integrity, and to control vibration, and pointing. Control bandwidths will extend to the hundreds of Hertz, as structures grow more massive and flexible. The great size of some of the space structures will require a large number of sensors and actuators and a highly distributed data processing architecture. Large structures will have controllers that can keep track of such characteristics as varying gross mass, center of mass, and vibration modes and frequencies, and can adapt to great changes in a structure, as when a platform is being constructed, modules are being added, or OTVs launched or docked.

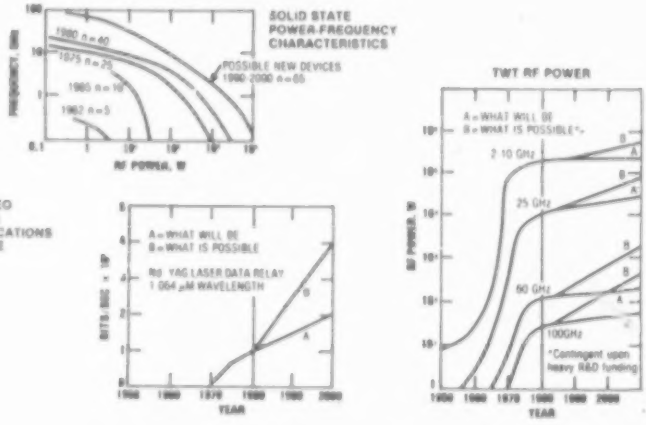
Unmanned OTVs will have active guidance, as will specialized craft for rendezvous and construction vehicles for building a platform. The guidance systems will furnish either minimum-fuel or minimum-time trajectories, having errors determined principally as a result of using the earlier mentioned navigation aids.

Builders of communication and data handling equipment for both civilian and military space use today must tax the state of the art to satisfy customers' desires. Despite making strides during the next forty years, technology will continue to lag behind demands.

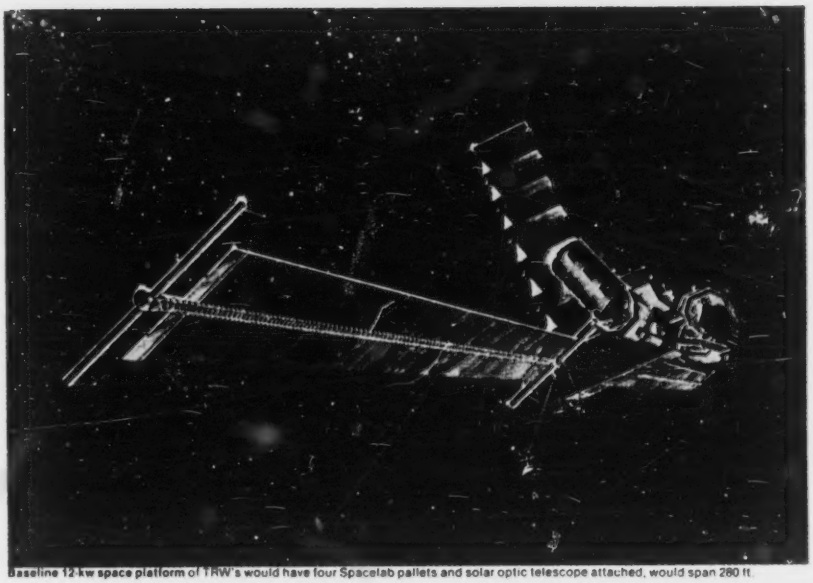
We see this prospect in the ever increasing demand for communications. Space is rapidly filling with satellites and their accompanying interferences. If we were confined to present and near-term technology, demand for service by 2000 would exceed the capacity of the number of satellites that can fit in GEO—120 operating at 12-14 GHz. This squeeze will lead to more and more international control in parallel with the international allocation of broadcast frequencies that began in the 1920s. As indicated earlier, means are available to prevent saturation.

Replacement satellites will operate at higher frequencies, have smaller antenna side lobes, and use beam shaping and polarization techniques. By 2020 large communications structures will have supplanted the satellites we know today. They will use steerable spot beams for communication of broadcast TV and electronic mail directly to users. On-board data processing will permit using the communications paths to maximum capacity.

F-7 COMMUNICATIONS TECHNOLOGY TRENDS INTO THE 21ST CENTURY



Lasers at visible or near-visible frequencies may begin to replace RF for communicating between Earth satellites (F-7). They will be immune to accidental or deliberate radio interference. Coded laser links may also connect spacecraft outside the solar system to a deep space relay station in GEO. Such links will handle adequate imaging data rates from the nearer stars, rates impossible by microwave with foreseeable antenna apertures and power because of its much broader beam. Laser communication will



Baseline 12-kw space platform of TRW's would have four Spacelab pallets and solar optic telescope attached, would span 280 ft.

be used to reduce considerably the size of some spacecraft, but microwave will remain the preferred frequency for Earth links.

Communications technologies that will be developed between now and 2000 and applied in 2000-2020 include:

- Multibeam antennas from 1 to 18 GHz and above.
- Phased array antenna feeds.
- Solid state, traveling wave tube, and field effect transistor (FET) amplifiers.
- General extension of useful RF bands to 40-100 GHz (F-7).
- Lasers for intersatellite and extra-solar system communications.
- Low-cost ground terminals.
- Message switching.

High power solid state transmitters, high-frequency-band operations and large bandwidth channels, large antenna farms (and feeds) for multibeam spot coverages, time division multiple access techniques, and automatic adaptive on-board traffic management will be highly developed by 2000. T-5 estimates the range of communication parameters in the early 21st Century.

The economics of communication satellites and multisensor Earth observation and military surveillance spacecraft in 2000-2020 will dictate data rates on the order of 10^9 bps. Many imaging sensors in this era will generate 10^{11} bits per frame, about 100 times as many bits per frame as 1980 sensors.

For lengthy space missions, especially to the outer solar system, the self-test and repair computer and other fault-tolerance autonomous maintenance approaches will raise the reliability of all systems using computers. Computers will make use of redundancy in such ways as by voting logic, element switching, system reconfiguration, diagnosis in real time, and strategy modification.

On-board decision-making will also allow more

T-5 COMMUNICATIONS TECHNOLOGY IN THE 21ST CENTURY

Parameter	Range
Frequency, GHz	UHF, C-band, Ku band, Ka-band
Power	
d.c.	25 kw_e
RF	8 kw_{rf}
Bandwidth, MHz	5500 MHz without frequency reuse
Beamwidth, deg	Global coverage to 0.25° Multibeam beamwidths
Antenna dimensions	5-30 m diam single reflector 10 m × 50 m array
Beams/spacecraft	Up to 100 simultaneous beams per spacecraft

complicated sequences calling for close cooperation between sensors and actuators.

For most satellites on-board navigators will supply orbital state information to the ground.

Most satellites will supply almost all their own orbital state information to the ground from their on-board navigators. Some, such as navigational support and abandoned satellites and space debris, will have to be tracked. Tracking will be done from the ground and space by radio and laser transponders and radar and lidar. Radar and lidar will be able to track out to geosynchronous orbit.

The tracking system will maintain a precise catalog of debris and inactive satellites and predict operational conflicts or collisions twenty-four hours in advance. This service will be most important to large space structures.

Tracking from the ground will determine position to 1 cm out to geosynchronous altitude for targets with RF or visual cross-sections of 0.1 m^2 or more.

As spacecraft proliferate they will have to be more autonomous if command and control are not to be overtaxed. Few will need individual support. They will share services such as navigation measurement and data relay, and will have a backup "safe hold" status in which they will need no external support but may be able to operate in only a limited way.

Thus, each spacecraft will exercise its own control, navigation and health monitoring with only occasional outside analysis of telemetry and delivery of system commands as supplements.

By the turn of the century life support systems will be closed and depend minimally on resupply from Earth. Intensive space agriculture will supply half or more of the crews' food, but animal husbandry will have to await further development. Fully recycling both breathing oxygen and water will reduce stores of makeup water to near zero and oxygen to negligible quantities.

Artificial gravity for space habitats will restore a more "normal" psychological environment for space workers and (perhaps) their families in long residence.

The natural radiation at high orbits will remain an impediment to extended extravehicular operation. Space suits with metallic foil shielding will be used for unscheduled tasks demanding EVA, but men will ride in protected small space vehicles with advanced manipulator devices to do the bulk of construction and other tasks outside the pressurized habitats and large transport vehicles.

Space suits will reject metabolic heat by radiation rather than by evaporating water. Advanced CO_2 regeneration will extend the allowable EVA duration to that of a long workday.

Routine servicing and resupply in the 1990s will support sustained operations, including a space center, in LEO and sorties to GEO. Servicing will be done by both manned and teleoperator vehicles.

Most servicing and repair will be done by removing expended or faulty equipment modules and replacing them. Limited repairs will be performed on the spot by man, but most repair will be done by taking the equipment back to the shop—a fully staffed space base—or will be done after return to Earth. Only very large refurbishment operations will require return of a satellite to Earth, since "full service" space bases will be in orbit.

Shuttle-type tankers will perform the majority of fluid resupply in space. They will either refill vehicles directly or deliver to space bases that will act as filling stations. Fluids will either come from Earth or be manufactured from Moon or other materials found in space.

From this picture of the technology base that will probably be developed in the '80s and '90s, we can project what will happen after the turn of the century. Missions from 2000-2020 will fall into the categories of commercial, scientific, exploratory, or military. The commercialization of space may span the gamut from communications platforms to proto-colonies in space, and include Earth sensing, manufacturing and materials processing, nuclear waste disposal, and lunar and asteroid exploration and mining.

The technological revolution of the past forty years set off by the invention of the transistor and other modern solid state devices is not expected to be repeated in the next forty years. The development of faster, denser, lower-power electronic devices will allow considerable improvement in communications systems without any new major inventions. With this assumption, it is possible to predict the state of commercial communications in 2000-2020.

By 2000, the present operational frequency spectrum will be unable to handle communications and remote sensing demands. In particular, the upward link of 6 GHz and down link of 4 GHz (C band) will be saturated in the late 1980s. The 12 GHz up and 10 GHz down (k_u band) will be saturated in the late 1990s. Even with the expected new technologies for frequency reuse, such as polarization and TDMA, these lower frequency spectrums will be unable to carry the traffic.

The overall demand for telecommunication services will grow by about a factor of five, and that carried by satellites will increase by at least a factor of ten. To alleviate the inevitable telecommunica-

tions log jam, another frequency band will be added—either 30/20 GHz or 45/40 GHz.

These bands will have the wide-band capacity for transmitting video at the same time they carry voice and data.

Early in the next century, holding teleconferences among participants on opposite sides of this country and throughout the world will be commonplace. Mail, newspapers, magazines, and other publications will be available directly in homes using dataphone and fax techniques. Most homes in developed countries and communities in developing countries will be able to receive broadcasts directly from satellites, and quite a number of government agencies and industrial organizations world wide will be able to communicate directly with satellites. Despite these new services, voice service will continue to account for a major portion of the demand.

The following communications satellite advanced technologies are expected to be operational in 2000:

- Multi-beam scanning antennas. They will allow a single satellite to service many different areas with many different transmissions.
- On-board switching and processing.
- High-power, all-solid-state systems.
- Low-noise, high-frequency-band transmitters and receivers.
- Inexpensive high frequency Earth terminals.
- High frequency components to support communications satellites, such as GaAs FETs for low-noise receivers and power amplifiers.

As an example of the communications systems that will have a major impact, F-8 describes a personal communications wrist radio system that will probably be in operation in the early years of the next century.

Remote sensing of the Earth from orbit will grow to span a portion of the electromagnetic spectrum having wavelengths differing by more than six orders of magnitude (0.3 μm to ~100 cm and possibly beyond). Powerful active sensors will be added to the arsenal. Most data will be selectively and automatically processed in space and relayed among special orbital centers for distribution to scientific, government, and business users.

The environmental satellite system of the future will combine manned and unmanned orbiters carrying advanced remote sensors that interact with remote sensors on land, in the ocean, and the atmosphere. What is sensed by one sensor will control the actions of other sensors. In this way the maximum amount of environmental information will be gathered through the minimum amount of collected data. Unmanned environmental spacecraft will operate at both geosynchronous orbit and highly elliptical, 12-hr, high-inclination orbits.

Constant improvements in sensors, data handling, and interpretation during the next twenty years will lead to routine acquisition and use of diverse resources data. Resource sensing will then

F-8 WRIST RADIO COMMUNICATIONS SCHEME

PURPOSE
To allow citizens to communicate through exchanges by voice, from anywhere

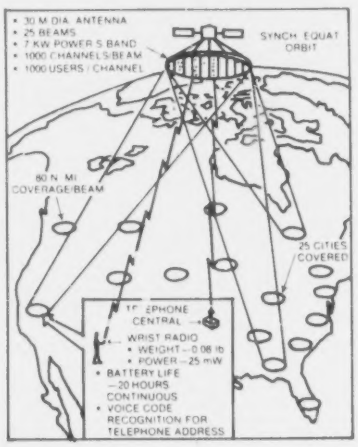
RATIONALE
Mobile telephones are desirable, but should be wrist worn. Many mobile users want communications

CONCEPT DESCRIPTION
Multichannel repeater and wrist transmitter-receivers connect people anywhere. Voice code recognition address (phone number)

CHARACTERISTICS
- Weight—4170 kg
- Size—30 m diam antenna
- Rad power—21 kW$_e$
- Orbit—Synch Equat
- Constellation size—1
- Life/servicing period—10/3 years
- Time frame—1990
- IOC cost—320 M$

PERFORMANCE
1 000 000 people in each of 25 cities can communicate. 25 000 simultaneously using normal voice

BUILDING BLOCK REQUIREMENTS
- Transportation—Shuttle and tug
- On orbit operations—automated or manual servicing unit
- Subsystems—attitude controls, antenna, processor
- Technology—large multibeam antenna, multi-channel transporter, LSI processor, multi-access techniques
- Other—wrist transceiver, LSI technology



be directed toward refined synoptic exploration of the planets, their moons, and other bodies, especially the asteroids.

Basic and applied research conducted in the late 1980s and 1990s will demonstrate that materials for commercial exploitation can be produced in space. We cannot say what the products will be or exactly how they will be made.

From among materials on which space research is being done, those that look as though they could be commercially exploited at the turn of the century include pharmaceuticals, infrared detector crystals, LSI circuit substrate, inertial configuration fusion targets, laser optics glass, large-particle monodisperse latexes, aligned magnets and ferromagnetic materials.

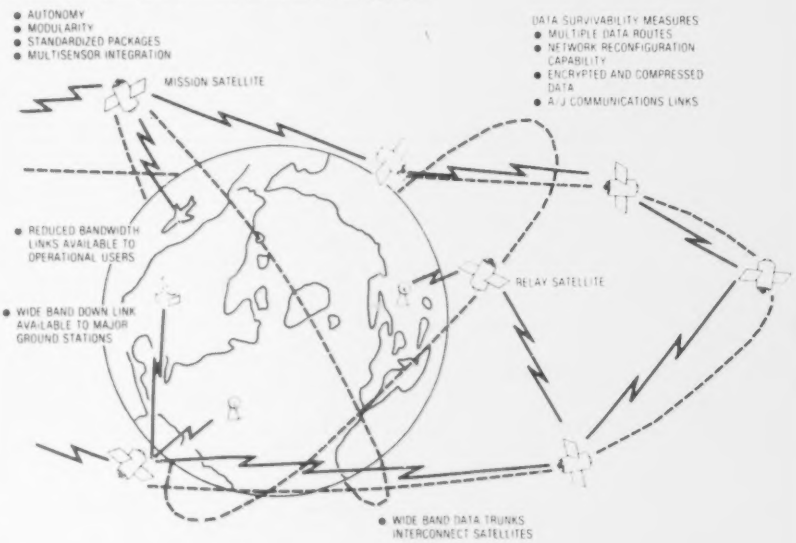
As an adjunct to terrestrial nuclear waste disposal, the removal by spacecraft of certain long-lived radio nuclides from the vicinity of the Earth has been studied since 1972. Too much nuclear waste is produced to dispose of it all in space with foreseeable available space transportation. However, removing from Earth the long-lived hazardous wastes such as the actinides, plutonium-240, americium-241, technetium-99, and iodine-129 would eliminate the long-term hazard. AIAA proposed a scheme in a January 14, 1981, position paper, "Nuclear Waste Disposal in Space."

The scope of lunar exploitation during the early 21st Century will depend upon making progress in using cislunar space and exploring with unmanned lunar missions during the 1990s. Even now, we know the Moon can be a substantial source of oxygen and structural materials for use in space. However, discovery of significant concentrations of high value minerals or frozen gases and liquids—especially water beneath the surface or in perpetually shadowed polar regions—would make exploitation more likely. Readily available water would make establishing self-sustaining colonies much easier and reduce transportation costs by supplying the raw materials for hydrogen and oxygen propellants.

Even if the industrial possibilities of the Moon are not realized, research facilities will probably be placed there. Near the lunar poles there exist constantly dark regions well suited to low temperature experiments. The lunar far side is an outstanding location for a major radio astronomy observatory.

At least some limited lunar research facilities seem likely to exist by 2000. Extensive manned lu-

F-9 SURVIVABLE MILITARY COMMUNICATIONS NETWORK CONCEPT


• AUTONOMY
• MODULARITY
• STANDARDIZED PACKAGES
• MULTISENSOR INTEGRATION
DATA SURVIVABILITY MEASURES
• MULTIPLE DATA ROUTES
• NETWORK RECONFIGURATION CAPABILITY
• ENCRYPTED AND COMPRESSED DATA
• A/J COMMUNICATIONS LINKS
MISSION SATELLITE
• REDUCED BANDWIDTH LINKS AVAILABLE TO OPERATIONAL USERS
• WIDE BAND DOWN LINK AVAILABLE TO MAJOR GROUND STATIONS
RELAY SATELLITE
• WIDE BAND DATA TRUNKS INTERCONNECT SATELLITES

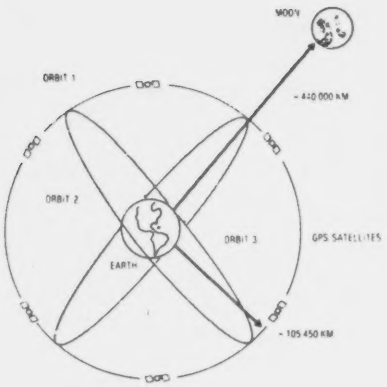
F-10 VERY SURVIVABLE GLOBAL POSITIONING SYSTEM

PURPOSE:
VERY HIGH SURVIVABILITY

CHARACTERISTICS:
96-HR ORBIT (105 × 450 KM RADIUS)
18 SATELLITES
CONUS UPLINKS

PERFORMANCE:
SAME AS 24 SATELLITE BASELINE GPS

TECHNOLOGY ISSUES
MAINTENANCE OF ACCURACY WITH LESS FREQUENT UPLINK OPPORTUNITIES
ORBIT MAINTENANCE AGAINST PERTURBATIONS



nar missions would make significant propulsion demands. However, such missions would establish permanent manned facilities perhaps approaching the scope of colonies. These facilities would carry out applied lunar research, possibly manufacture propellants, and produce structural materials or other goods for use on the Moon or in space.

An asteroid landing may be conducted around 2000, and an unmanned sample return mission, about ten years later. Substantial asteroid exploitation will not occur before 2020. Asteroid missions could be carried out much sooner if early missions show an economic payoff big enough to rally support.

Post-Spacelab experimental free-flying manned platforms and facilities like the Space Operations Center (SOC) for a range of applications, including development of materials processing techniques in the 1990s, will pave the way for permanent habitats or "proto-colonies" in low Earth orbit around the turn of the century. These proto-colonies would house several hundred people under benign living conditions, including simulated gravity by rotation, and partially closed air, water, and waste systems. The residents would carry out a wide variety of physical and biological scientific investigations, space technology development, and manufacturing. Such proto-colonies may be international undertakings. Later they may lead to manufacturing plants and permanent habitats in geosynchronous and other orbits.

Basic physics experiments in space in 2000-2020 will extend the volume and duration of those conducted in the last two decades of this century. Fluid dynamics and plasma physics experiments will be conducted on large scales of space and time. Man-made problems, natural ground disturbances, and a baseline limited to the Earth's diameter have prevented detecting gravitational waves. The short baseline restricts the observable wavelengths to extremely short-period accelerations of very great masses, such as those produced by supernova explosions. A network of gravity wave detectors in GEO or at Earth-Moon Lagrangian points may detect waves from such sources as pulsars and binary systems of two neutron stars.

In optical astronomy apertures larger than 3-4 m will be needed to surpass the Large Space Telescope projected for the 1990s. Larger apertures would gather even fainter light.

In radio astronomy, space operation offers the opportunity to observe frequencies below the ionospheric cutoff (about 5 MHz), to resolve small structures with interferometers with very long baselines, and to avoid man-made and natural terrestrial background. An interferometric network will likely be established with several receivers in GEO between 2000 and 2005. The baseline may be extended to the Moon by 2010. A manned or man-tended observatory on the lunar far side, established about 2015, will completely avoid terrestrial background.

If we assume low activity in planetary exploration in the next 20 years, then by the turn of the century we will still not have flown complex orbiters around the outer planets, sent landers and rovers to their

moons, returned samples from Mars and other planets, or performed many other demanding missions. Assuming that the goals of scientific exploration of the solar system do not change substantially, these missions would still be planned. However, development of extremely capable in-situ instruments could reduce the advantages of sample return over a surface rover. Advances in robotics would make a surface rover even more attractive. Such a change would affect the need for advanced propulsion. A manned Mars mission would strain propulsion technology in the early years of the next century. Judicious use of aerodynamic braking at Mars, and manufacturing propellant from water at the polar caps or in subsurface deposits would substantially ease the propulsion needed. Nuclear propulsion will probably be used for advanced missions, unmanned or manned, late in 2000-2020.

Most outer planet flybys fall in the category of galactic probes, since they reach solar system escape velocity. However, their velocities will be too low and communications too limited to satisfactorily carry out a true galactic mission. A worthwhile extra-solar system probe would require a velocity well beyond those to which we have become accustomed. Of the candidate propulsion systems in 2000-2020, only nuclear electric has any possibility of application and, even so, will have to perform substantially better than it would for planetary missions if such missions are to be accomplished in a reasonable time—less than 30-50 years.

If the technology for creating super-efficient solar sails in space can be mastered and a vehicle carried by such a sail brought to a starting point near the Sun, very substantial velocities are possible. Nuclear fusion propulsion may also have potential. Certainly, there will be a substantial interest in extending our frontiers beyond the present solar system in the early 21st Century.

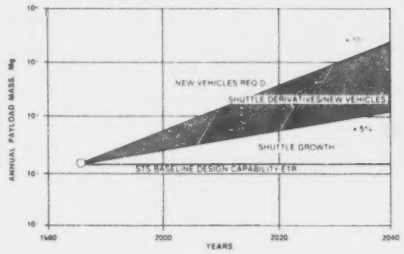
As space systems prove themselves during peacetime, and crises and survivability issues are resolved, many more military functions will be performed from space. Manned facilities will create new opportunities for military space operations.

Military systems will be called upon to defend civilian satellites as more high-value operations are conducted in space, and may well be integrated into some commercial and/or government systems for economy and protection. However, most military systems will continue to be dedicated.

Space-based weaponry may contribute to global stability, although in accordance with international agreements, orbital weapons of mass destruction will probably not be developed.

Typical military systems may include an integrated, survivable military communications network (F-9) giving a flexible, robust military command, control, and communications system and a highly survivable navigation system (F-10) for secure, reliable global positioning.

F-11 ANNUAL PAYLOAD TO LOW EARTH ORBIT
STS baseline: 30 Mg/flight, 50 flights/yr.

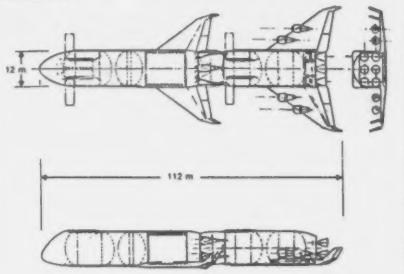


Separate military launch systems would permit more flexible scheduling than if all military missions relied on civilian launchers.

The missions described previously will depend not only on specific technologies and development of the required spacecraft, but also on large-scale support from transport vehicles, ground and orbital operations control facilities, and space construction bases.

The first step into space from the Earth's surface to LEO receives most attention today. Planners are increasingly realizing that the subsequent steps to higher energy orbits will require a new Orbiter-compatible OTV that is better and more economically matched to the missions of the late 1980s and early 1990s than the present IUS and other smaller stages, modules, and kick motors. Thought will have to be given to vehicles and propulsion stages for cislunar space, and for heliocentric and, later, galactic flight early in the 21st Century.

F-12 ADVANCED SMALL REUSABLE TWO-STAGE SERIES-BURN HLLV



After the Shuttle makes its early flights, its performance will be slowly raised by reducing mass and improving the main engine performance by increasing effective jet velocity. Turn-around time and operational costs will drop while useful life will increase. The thermal protection system, External Tank (ET), and Solid Rocket Boosters (SRB) will be improved. In the late 1980s or early 1990s a parallel burn Liquid Boost Module will probably be added to the aft end of the ET.

In the late 1990s a Liquid Propellant Rocket Recoverable Booster will replace the SRB both to improve payload and reduce cost.

Around 2000, traffic to LEO may have increased sufficiently to justify a completely reusable space transportation system. This system will operate like a commercial airline, carrying personnel and cargo into LEO at reduced cost. Early in the 21st Century the Orbiter will be able to transport relatively large numbers of persons into orbit for work or play with a passenger module in the cargo bay.

All these changes will increase the payload of the Shuttle 5% per year above baseline (F-11). When demand starts rising faster than 5%, new manned and unmanned vehicles will be built.

A derivative unmanned heavy-lift launch vehicle will carry more massive and larger cargos than the present Shuttle payload bay accommodates. An expendable shroud will cover the cargo during its rise through the atmosphere. After burnout the SSME will return to Earth in a recoverable module.

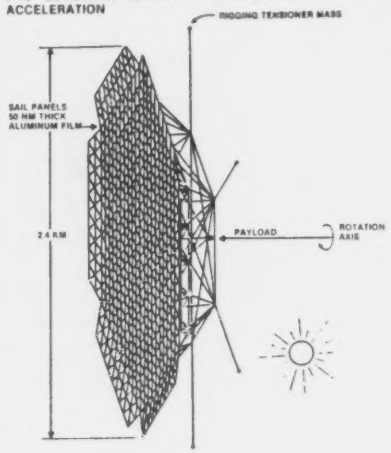
An advanced heavy-lift launch vehicle (HLLV) will be completely reusable and will lift four times the payload of the present Shuttle (F-12). The version in F-12 is a recent control-configured vehicle design. Its two series-burn stages give a large reentry cross range so that it can service many key orbital altitudes and inclinations.

A vertical takeoff single-stage-to-orbit vehicle will have an insulated structure, aluminum load-bearing tanks, and one dual-fuel and three oxygen/kerosene engines. It will have a mass of 1140 Mg at liftoff, 83 Mg dry, a payload capacity of 29.5 Mg into a 185-km eastward orbit from ETR, and a payload bay measuring 4.6 × 18.3 m.

An even more advanced horizontal takeoff, single-stage-to-orbit vehicle will incorporate multicycle airbreathing engines and a metallic, multi-wall thermal protection system. Besides transporting people and cargo to LEO, it could carry out space sorties, rescues, and other special flights or stay in the atmosphere as a hypersonic military and civil transport.

When traffic into LEO has increased sufficiently and requires frequent trips, a ground based

F-13 ULTRATHIN METAL-FILM SOLAR SAIL WITH 10^{-4} G ACCELERATION



multigigawatt laser system may be used to heat a propellant to high effective jet velocities for efficient and economic transport. Or, electrically driven rail guns or mass drivers may be used to launch heavy payloads to LEO.

Tethers extended from space stations for hundreds of kilometers may transport items to LEO and between LEO and GEO.

As geocentric space operations develop in the early 1990s, new orbital transfer vehicles for flights between LEO and GEO will most likely use modified RL-10 engines. Smaller high performance stages will also be built for transfer between orbits.

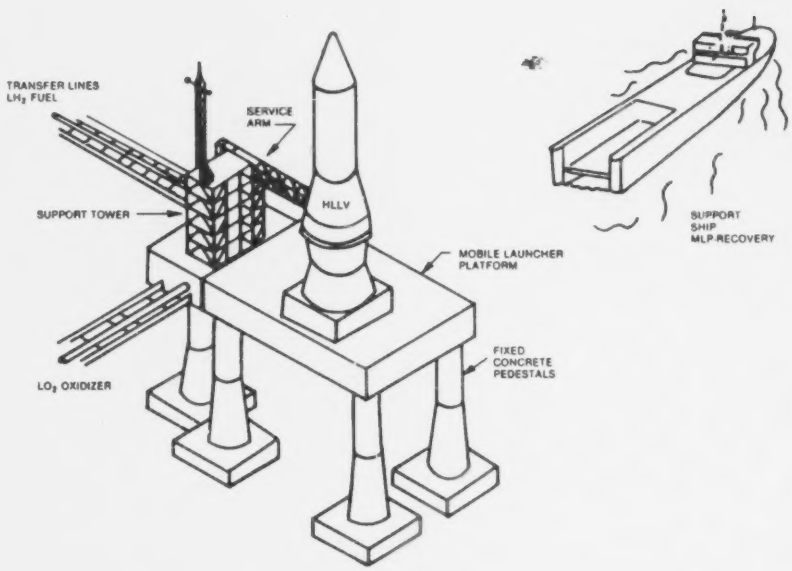
Though chemical rocket OTVs could, and probably will, be used for missions in cislunar space, a number of studies have shown that nuclear- or solar-electric powered OTVs could be comparatively flexible, effective, and economic.

Chemical rockets can continue to launch solar system explorers to the end of this century and beyond. Solar electric rocket stages will be used on a number of heliocentric missions before the end of the century and for most inner solar system missions in the 21st Century.

Nuclear electric rockets will be the workhorses of solar system exploration in the first 20 years of the next century. But much analysis and technology development is needed in the next twenty years to ready subsystems.

Depending on individual mission models, solar sails may propel heliocentric and extrasolar system

F-14 HEAVY LIFT LAUNCH VEHICLE OFF-SHORE LAUNCH SITE



craft in 2000-2020 and beyond. By exposing a very large area of extremely thin metal film to the solar wind the sail shown in F-13 would produce a respectable 10^{-4} *g* thrust with no expenditure of reaction mass.

As STS traffic develops in the late 1980s, emphasis will shift to improving effectiveness and economy of operations to insure routine, safe, and highly reliable performance of missions in the late 1990s. By the turn of the century, traffic into and in orbit will require highly sophisticated facilities and operational techniques.

An offshore launch site will probably be needed after the turn of the century. It may be at Cape Canaveral or near the equator. Experience and studies yet to be performed will determine the site. Frequent flights of HLLV would call for an offshore launch platform of the sort shown in F-14.

OTVs will be based at SOC or similar space platform. A SOC will be in operation by the mid-1990s or 2000 at the latest, and an attached OTV hangar will protect these vehicles from space debris and accommodate service and maintenance.

Equipment and techniques will be developed for extended extravehicular activity by astronauts, robots, and teleoperators—restrained and free flying. The robot's versatility in assembly and construction will save considerable payload mass because the same machine can perform a variety of operations. A computer in the robot exerting real-time control will handle many operations more reliably and effectively than a man guiding movements remotely.

Large structures in space at first will be fabricated on Earth and unfolded in space, then assembled in space, and still later partially fabricated as well as assembled in space.

Fabrication will become almost entirely, and assembly, considerably automated. Space construction personnel will use the same skills throughout the transition, but the skills will have a different focus. Man will continue to monitor the process and handle with machinery the subassemblies, but he will spend much more time maintaining the facil-

ity. The greater the automation, the greater the complexity of the structure.

Antennas will, for the most part, be ground fabricated and unfolded in space. This will hold for all types of antennas, reflectors, space-fed phased arrays, or hybrids. They will have powered mechanical joints and structural members and tension stays of composites to minimize thermal distortion.

A limited number of medium-sized antennas, with very exacting surface tolerances will be built on the ground. These antennas will pay for their superior figure with high weight and will usually need to be assembled in their operating orbits.

Platforms will be built in all three ways but only the very largest will warrant space fabrication. A typical platform in the year 2000 will have an area of about 1000 m^2 with structural members mostly 5-15 m long. By 2020, some platforms will have grown to 10,000 m^2.

Manned facilities will be well established by 2000. They will be able to carry out construction in 2000 and will house early space factories by 2020. The factories will process raw materials into usable materials for construction of advanced communication satellites, observation platforms, defense systems, and interplanetary vehicles.

Around the turn of the century some large space structures will still be deployed from the Shuttle payload bay or assembled and tested while attached to the orbiter or in adjacent space.

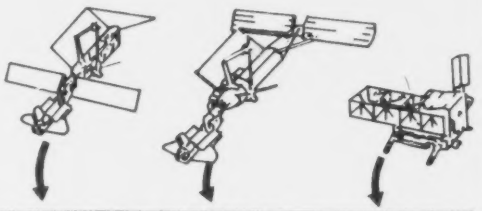
In 1990-2000, the only construction base will be in LEO (T-6). This platform will be an upgraded 25-kw_e power module with a workbench 30 m long. A crew will man it only when the Shuttle Orbiter is docked to it.

By 2010-2020, SOC or other space stations will have taken over as the LEO construction base. The stations will be bigger than the power module building block, have a simple cargo and machinery handling system, beam builders for economical in-orbit fabrication and assembly of space structures, and moderate power and will serve as a space depot. Its crew will remain on board between Orbiter visits. By 2000-2010, a line shack in GEO will perform the same functions as the earlier LEO power module.

Large space platforms will need only modest support facilities on Earth. Neither reprocessing materials for space fabrication nor fabricating building block structures on the ground will demand unusual new plants, with one possible exception. Some structures designed for ground fabrication and space unfolding need ground rigging and verification of the unfolding. This check means carrying out at 1 *g* a maneuver designed for zero *g*. Doing so presents a technical challenge and seems to demand buildings and simulation equipment bigger than the article to be unfolded.

In an extrapolation of technology covering 40 years, present events have enormous influence. Thus the review of space policy being carried out under George Keyworth's Office of Science and Technology Policy will greatly affect the accuracy of our conclusions. The space policy will probably emerge some time after the National Security Council makes its recommendations this summer. Judging from the administration's past tendency to stick with present space systems, which could be changed by international events, we judge the "guesstimates" in this article may be optimistic.

T-6 SPACE CONSTRUCTION BASES



	2000		2020		SPS	
Characteristic	LEO	GEO	LEO	GEO	LEO	GEO
Platform	Pwr. module	—	SOC	Line shack	Const. base	Final assy / maint. base
Workbench L.	30 m	—	50 m	30 m	2000 m	1000 m
Rail system			Linear		3 dimn.	3 dimn.
Power level	20 kw_e	—	200 kw_e	20 kw_e	2·10 Mw_e	1·5 Mw_e
Depot function			Yes		Yes	
Habitation	Tended	—	Manned	Tended	Manned	Manned

A lunar mining base would use an electromagnetic launcher to send its products to a space-based factory.

SPACE

We will return to the Moon for private and government space developments, but lack the laws and international agreements to prevent conflict in such major space activities

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by George Mueller
System Development Corp.

The 21st century in space

Speculating on our future in space has been a pleasant diversion for space scientists and popular writers. Although most predictions have not proved accurate, no one really much cared.

Today, however, we have good reasons *to care* about what will occur in space in the next 25 years. I refer not only to the military threat, but to economic, political, and legal ramifications as well. Since space development appears to be accelerating, important actions should be started now that will permit the world's political and legal structures to cope with a "brave new solar system."

Technology not the determinant

A modern-day Nostradamus must be much more accurate than in the past. Unfortunately, our predictive tools today are not much better than they were in the 16th Century. To one degree or another, we have always been able to predict what *could* happen; the problem has always been to predict what *will* happen.

Consider our situation. We have the technology to support any reasonable space activity we can imagine for at least the balance of this century. We can—and will—accomplish many exciting and far-reaching space developments in the next two decades without the need for further technological breakthroughs.

Unfortunately for the predicter, *political* and *economic* factors will determine the course of events far more than will technological developments. Because of the vagaries of these essentially human factors, moreover, the prophet can only forecast trends that pass some test of reasonableness.

George Mueller directed the NASA Office of Manned Space Flight at the height of the Apollo program and led Shuttle and post-Apollo planning. He was subsequently president and chairman of the board of System Development Corp., president of the AIAA, and is currently president of the International Academy of Astronautics.

Fortunately, however, it is possible to describe some of the space activities we can expect to see by the turn of the century in terms of trends rather than specific timetables. These activities have the potential of greatly expanding both the physical resources and the knowledge of mankind, but they likewise will raise new and knotty legal issues that we have not had to face before.

First, and regrettably foremost, terribly effective weaponry could well be deployed in space by the year 2000, weaponry that can attack both satellites and space stations as well as targets here on Earth. Our goal must be to ease world tensions so that this weaponry will not be deployed. Otherwise, every accomplishment I forecast in this article will be in jeopardy. On the assumption that the world powers *will* draw back from military confrontation, I can confidently predict widespread space activities by the year 2000. We are already seeing an acceleration in the number of space projects being planned and carried out.

In 1980, for the President's Office of Science and Technology Policy, AIAA projected the non-federal demand for space transportation through the year 2000. It concluded that this demand would increase from the 1980 level of one equivalent full-orbiter payload to 25 such payloads annually by the turn of the century. This report was greeted at first with considerable skepticism. After all, since the projection assumed the advertised Shuttle payload capacity, and since it excluded military and other government missions, it implied a load on our Space Transportation System far beyond that

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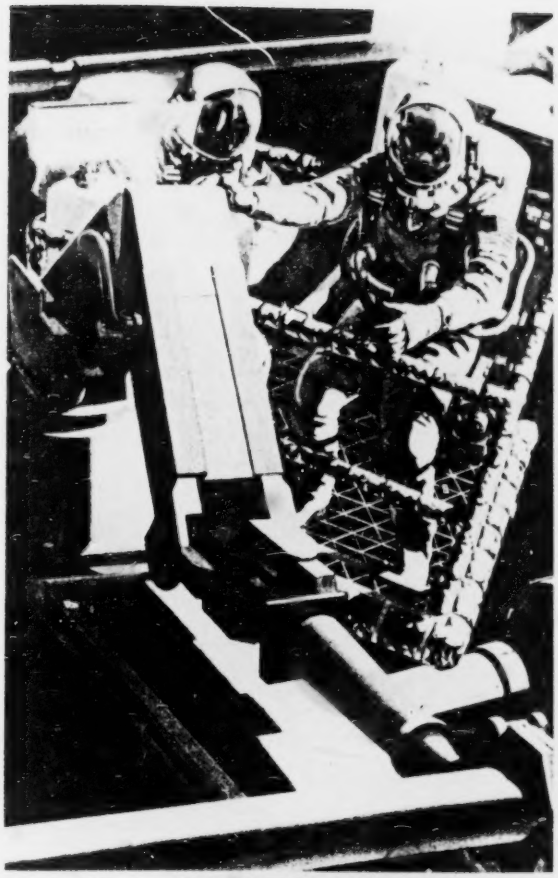
programmed for the Shuttle. Now the skepticism has all but disappeared. The high-traffic forecast of the Battelle Outside Users Payload Model (see graph) tracks the AIAA projections very closely for the next 10 years. (I have not included Battelle's longer-term forecasts because they use a "bottom-up" model which does not cover 1990-era programs not defined today.)

Many of the projected payloads add to our growing satellite communications capability. Indeed, experts expect the demand for communications to double in just the next four years. With present techniques, this demand would completely saturate the geostationary arc by the year 2000. We will be seeing new techniques employed to increase bandwidth and communications efficiency; some of these techniques have already begun to be deployed in recently launched satellites. Probably there will be larger communications platforms with time-shared multibeam antennas.

Global newspapers

Communication capacity has already surfaced as a legal issue. The World Administrative Radio Conference held in 1979 resolved to hold conferences in 1985 and 1987 to guarantee countries equitable access to the geostationary satellite orbit. Assuming the intertwining technical and legal issues will be resolved, by the year 2000 satellite communications will be beamed to any place on the globe at extremely low cost. Direct-broadcast newspapers created in this period will have an enormous impact in overcoming international and social barriers. By the same token, worldwide news distribution will grant broadcasters vast propaganda potential, and I see no practical way to impose a requirement for responsible, factual reporting. Newspapers with audiences of a few hundred thousand have not been able to achieve completely objective reporting—and tomorrow's audiences may number in the billions. This global audience will have to sort out the truth from reports of different broadcasters with differing viewpoints, but at least they will have access to differing viewpoints. Competitive reporting provides increased understanding and knowledge throughout the world.

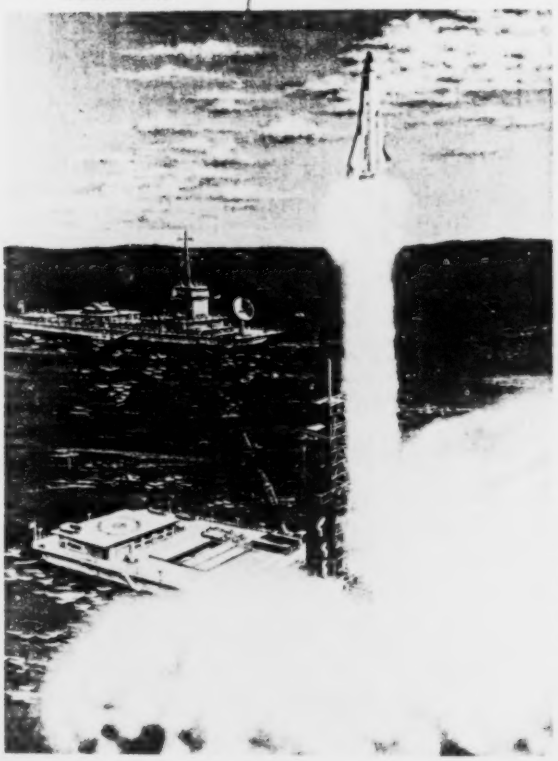


Efficient symbiosis of machines and people is essential to the development and assembly of large space structures and to the in-orbit servicing of scientific spacecraft, large multipurpose communications satellites, and space-based factories.

Newspaper broadcasts are by no means the only vehicles by which satellite communications can increase knowledge. By the year 2000 computers will provide access to the text of all the books and periodicals written since 1950. With a simple viewing device anyone will be able to acquire the knowledge contained in the libraries of the world (and, incidentally, play havoc with today's copyright laws). The impact of this development will rival the invention of the printing press.

On a less lofty plane, this same communications capability will dramatically alter the advertising and distribution of consumer goods. Suppliers will be able to advertise their products to billions of customers. We may well see a global interactive mail-order system. With that development, today's system of tariffs and protected industries will become obsolete.

A fully reusable single-stage-to-orbit dual-fuel shuttle lifts off from a barge. Such concepts tempt planners with their promise of lower mass-in-orbit and operational costs. Shuttle shows aerodynamic shape developed by NASA Langley Research Center. Illustration courtesy of System Development Corp.



I fully expect that the pressures of our dwindling terrestrial energy supply, as well as the serious climatological impact of increasing levels of combustion-generated atmospheric carbon dioxide identified recently by the Environmental Protection Agency and the National Academy of Sciences, will move us to derive energy from extraterrestrial sources (most probably solar power) collected outside the atmosphere, used in space, and beamed back to Earth.

The feasibility of a solar-power satellite has been much studied. Because of technical risks and costs, I do not believe it likely that a solar-power satellite will be built, at least in this century, but the prospects for a *lunar*-based solar power station are much brighter. As suggested by David Criswell, of the California Space Institute, it could be largely constructed using materials mined and processed from the Moon and asteroids. More than 90% of a solar power station can be created in situ without the great expense of transporting hundreds of thousands of tons of materials from Earth. Without significant additional technological developments, a pilot solar generating facility could be operating on the Moon in about ten years. By the early years of the next century, commercial-scale lunar-based solar power plants could be supplying a significant portion of the Earth's energy.

Moon power

The economics of the project are so attractive that it may well be the first of the lunar-based commercial projects. The UN should not delay in establishing an acceptable system of defining territorial rights on the Moon. If the lunar solar project is developed—and subsequently owned—by one nation, that nation would have a great advantage in lunar development. The lunar materials-processing plant surely would not be restricted just to building solar panels for long. Without some territorial apportionment, the first nations to begin developing the Moon would effectively own the Moon.

Presumably, the generated power would be sold to customers in any nation on a free-market basis. But the nations operating the facility might well elect to do otherwise. As terrestrial energy resources dwindle further in the 21st Century, the lunar source of power could be granted, or withheld, or differentially priced, based on national political or economic considerations. Such an approach

is not without precedent here on Earth. Such an act—or the threat of such an act—would certainly strain international relations and could restrict the potential of the project as a human resource.

One approach would be to have international ownership of the Moon and its resources. The nation or organization that develops each project might be given a lease, much as oil companies are granted leases to develop government-owned land. In return they would be required to sell the energy on an unrestricted basis at a fair market price. The problem lies in obtaining adequate return on the tremendous front-end investment required for such a project.

Space factories

This is not the only way to establish a system of territorial rights on the Moon. It may not even be the best. The point is that lunar development almost certainly will commence before 2010, and some acceptable system must be devised to avoid a clash of competing nations.

Further, we should not assume that space development will always be by national governments. By the year 2000 the private sector will have emerged as a factor in space industrialization, just as it has in satellite communications. Although projects of the magnitude of a lunar solar power system will undoubtedly be government-financed for the foreseeable future, many space factories may not be.

With the Space Shuttle flights of the next few years, many experiments will be conducted to determine the feasibility of space manufacture or processing. A sizable percentage of these experiments, I predict, will lead private corporations to invest in materials processing or other manufacturing in space.

We have already seen a highly successful materials-processing experiment designed by Johnson & Johnson and McDonnell Douglas using continuous flow electrophoresis (a process not very efficient on Earth) to produce urokinase, the pharmaceutical so effective in dissolving blood clots. McDonnell Douglas projects commercial operations beginning as early as 1986.

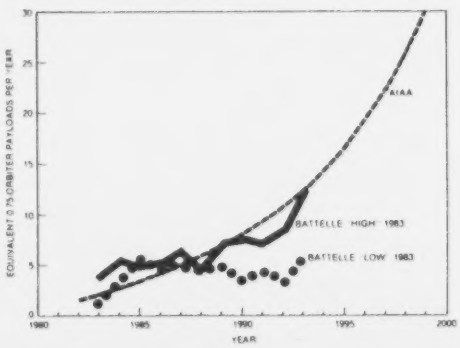
The concept of materials processing in space is certainly gaining acceptance. The 1983 Battelle study projects as many as 121 such payloads in orbit by 1997, 15 times more than the AIAA projected in its 1980 study.

Since both NASA and DOD appear to be phasing out launches of expendable vehicles such as Thor, Delta and Atlas Centaur, while allowing private operators to continue such launches, the only major government-operated space transporters will be the Shuttle and the Ariane. I doubt these two systems can meet the demand that is growing so rapidly.

This situation appears to call for the development of a second-generation Shuttle. Designed to be a fully reusable single-stage-to-orbit system, as suggested by Robert Salkeld of System Development Corp., a second-generation Shuttle would cut launch costs sharply—so sharply, in fact, that it would undoubtedly increase the demand, since far more projects would become economically attractive.

NASA has not shown strong support for a second-generation Shuttle. I believe that the private sector will invest in its own space transportation system. A number of firms are already seriously investigating the matter. Unencumbered by a bureaucracy, an expensive infrastructure, and a maze of regulations, private industry could operate a space transportation system much like an airline. With low launch costs, private industry could compete quite favorably with the Shuttle and Ariane. For this reason alone, I fully expect at least one private reusable space transportation system to be operating well before the end of the century.

To make such an operation feasible, space launches will be very different than they are today. I envision onboard checkout, minimum ground maintenance, and erector-type launch facilities (see illustration), and possibly manned vehicles



AIAA projections, supported by three Battelle Institute analyses, describe accelerating space development that will severely strain space transportation system capacity by the 1990s. As presented in *Astronautics & Aeronautics* in March 1981, this graph gave launch-demand projections for all non-federal payloads to be delivered by U.S. vehicles. It assumes a third of the foreign market will be captured by the U.S. AIAA made its assessment for the President's Office of Science and Technology Policy.

launched from barges—in international waters to avoid the most onerous of government controls.

These can hardly be considered radical concepts. Mobile erectors were used for V-2 launches 40 years ago. The Germans could roll a 46-ft V-2 into a field in Holland, fuel it, erect it, and launch it—all in 45 minutes. In the early '60s, erectors were used on the Atlas program to launch the 90-ft missiles; the legendary "Hollywood Hard" emplacements were designed to permit fueling, erection, and launch in only 20 minutes.

With proper forethought, the launch

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of the second-generation Shuttle will be far simpler than that of an Atlas, and certainly will be far less complex than the current Shuttle demands, for it will invoive servicing only a single completely reusable vehicle.

For such reasons I foresee private corporations operating routinely in space. In addition to undertaking transportation, materials processing, and other space manufacturing, private companies or consortia will, I believe, mount projects to recover extraterrestrial resources, most likely by mining asteroids. Since many asteroids are rich in platinum-group metals, which have a value now of more than $20,000 per pound, the return-on-investment potential from an asteroid-mining mission is sure to interest commercial companies.

As the private sector relieves NASA more and more of space development operations, the agency will be able to return to its originally intended role. I envision scientific missions, in particular planetary exploration, increasing sharply from the current low. Today's budget of around $200 million severely hampers this important part of our space program. Despite the spectacular success of Viking, Mariner, and Voyager, Galileo is the only major interplanetary exploration program now approved.

The program outlined last April by NASA's Solar System Exploration Committee (SSEC) seems well thought out. It encompasses three initial missions: a Mars geoscience and climatology orbiter, a Titan probe and radar mapper, and a comet rendezvous and asteroid flyby. All would be launched in the 1990 era, and would be followed by missions such as a Mars surface probe, a Venus atmospheric probe, Saturn and Uranus flybys and probes, and a Saturn orbiter.

These missions, it seems to me, have an excellent chance of gaining approval and funding. Only one completely new spacecraft, the Mariner Mark II, would be required under the initial SSEC proposals, since the Mark II's modular design would be reconfigurable for other probes. Particularly if missions are conducted by international collaboration, I anticipate much solar-system exploration before the turn of the century.

The discovery that perhaps could change most the course of space exploration and even the future of mankind would be success in the search for extraterrestrial intelligence. Contacting other intelligent life would completely change our provincial world perspective of man's role in the universe.

Even if contacts elude us, space will undoubtedly stimulate many other projects in the next 25 years. With certainty I predict diversity and the unexpected. But we are not prepared in terms of laws and international agreements to deal effectively with what we *know* will come in space. Developing law to govern here on Earth took centuries. We have perhaps a decade to develop a comprehensive *and acceptable* body of law for space. We had better drop the postures of national competition that characterized our start in space and develop instead a spirit of international cooperation. Otherwise, we put at risk access to the incalculable resources of the universe.

CHAPTER THREE

HISTORY OF NASA AND ITS RELATIONSHIP TO UNITED STATES SPACE POLICY

By George N. Chatham
Specialist in Aeronautics and Space

I. INTRODUCTION

The purpose of this chapter is to sketch the origins of U.S. civilian involvement in aeronautics and space activities with particular reference to Government organizations of which the National Advisory Committee for Aeronautics (NACA) was the first, and of which the National Aeronautics and Space Administration (NASA) is now the largest and most important agency.

Short of a multi-volume effort, it is not possible to trace all aspects of this history and the policy issues which have surrounded the growth of the U.S. capability in space. The chapter puts into historical perspective the creation of NASA and treats selected policy issues which arose during its growth and evolution and how these were resolved. Unresolved issues remain, and Chapter Two has identified the principal ones of these issues.

II. FROM THE WRIGHT BROTHERS TO SPUTNIK

A. After the Wright Brothers Flight

The Wright brothers [1] succeeded in a controlled, straight line, powered flight on December 17, 1903. No one understood better than the Wrights how much they had yet to accomplish to evolve a maneuverable and stable vehicle from this first one capable of only a shallow, nearly ballistic flight.

Intensive work and flight trials continued over the next three years, mostly from an open pasture near Dayton, Ohio, and the point was reached where a maneuverable flying machine could be demonstrated. Although the belief was still strong in the United States as well as Europe that powered, manned flight was not possible except by buoyant flight, the Wrights had accumulated a number of eyewitnesses who knew that, despite the plentiful expert testimony to the contrary, man had indeed achieved powered flight. Among these eyewitnesses were a few wealthy Americans who were prepared to back the Wrights, and an even larger number of influential Europeans.

Incidental to their research, the Wrights had obtained for their designs and inventions patent coverage that would warm an in-

[1] Kelly, Fred C. The Wright Brothers. New York, Ballentine Books, Random House, 1975.

Reproduced from Chatham, George N. History of NASA and its relationship to United States space policy. In Congressional Research Service. United States Civilian Space Programs: 1958-1978; report prepared for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives. Volume 1. Washington, For sale by the Supt. of Docs., G.P.O., 1981. p. 29-68.

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vestor's heart and bring despair to competitive designers and inventors. Objections to the Wright patent "blanket" were strenuous,[2] but to no avail. For example, the Wrights' system of lateral control was to warp the wings, a technique they never saw the need to abandon. According to the courts, other systems, e.g. the independent movable control surface of Curtiss, or the modern system of a deflectable panel on the outer trailing edge of the wing, were all covered by the Wrights' claims. Such was the power of the Wrights' legal position that, in those early days, no one in the United States could contemplate commercial construction of aircraft without making a financial arrangement with the Wrights. Air shows, the most lucrative and only practical civilian use for the airplane, routinely paid large sums to the Wrights in advance to curtail legal stop orders or successful law suits.

There can be no doubt that the Wrights' patent position and penchant for swift legal enforcement was a significant factor in retarding aeronautical development in the United States compared to Europe in the years just prior to World War I. However, it was not the only factor, or perhaps not even the most significant one.

During the period between 1906 and 1908, the Wrights began serious efforts to "sell" their airplanes. Their price of $25,000 (which included flying lessons) was today's equivalent of about $180,000.[3] The Wrights thus greatly simplified their marketing effort. It would be an item for the consideration of governments or perhaps the more daring of the world's extremely wealthy.

The United States, being the dominant power in the Americas and separated from Europe by a distance still considered vast, saw the airplane as a curiosity of dubious military value—but would witness a demonstration, scheduled August 28, 1908 at Fort Myer, Virginia, but only following a lengthy paperwork routine.

Aeronautical interest in Europe sharply contrasted with that in the United States in nearly every major aspect. Within a geographic area about equal to that of Texas, a tight cluster of traditionally competitive nations were in a temporary state of restless and vigilant peace. These governments were far more interested in the potential military utility of flight. Also, each nation contained its own group of wealthy industrialists and each nation contained another group not to be found in the United States, a wealthy nobility. Further, manned flight by means other than buoyant flight had been a subject of speculation and research for hundreds of years.

In the interest of tight schedules for promised demonstrations in the United States and in Europe (France), the Wrights decided to separate: Orville was to fly in the United States and Wilbur in Europe. The demonstrations at Fort Myer were successful in dispelling the long-standing suspicion of the press and much of the public that the Wright aircraft as well as the Wrights themselves were fictitious. The test requirements were interrupted by a crash which injured Orville and killed a military passenger, Lt. Thomas Selfridge.

Wilbur, in Europe, flew initially from Hunaudieres race track near Le Mans. His first flight was enough to crush the suspicion of the

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[2] Loening, Grover, Takeoff Into Greatness, New York, G. P. Putnam's Sons.
[3] Calculated from Consumer Price Index Series which shows today's dollar has the buying power equal to $0.14 in 1910.

French press that he was a "bluffeur" [4] and to make him an instant hero. With his continued flights, his fame became international and his passengers included a rich sampling of Europeans including English nobility, high-ranking military and wealthy industrialists. Also in his audience were some of Europe's aspiring and experienced successful producers of new designs which were to evolve swiftly under the pressure of war into aircraft far in advance of that achieved by the Wrights.

As the winter of 1908 began to produce poor flying weather, Wilbur moved to Pau, a resort at the foot of the Pyrenees, where he was joined by the recuperating Orville and their sister, Katherine.

As their demonstrations continued through the spring of 1909, it seemed to the Wrights that, with the numerous agreements they had developed; with a French-Wright Company, a German-Wright Company and an Italian-Wright Company, along with their company in the United States, they could look forward to a bright future in which they and their now immortal "Wright Flyer" would dominate world aviation.

After a triumphant return to the United States in 1909, Orville successfully completed his military test and sold a few Wright Flyers to the Signal Corps and to the Navy. However, he found that the manufacture and sale of his aircraft was relatively small on potential income compared to that possible from air shows. For the purpose here it will suffice to say that following Wilbur's death, May 30, 1912, Orville continued a highly profitable air show career as he steadily refined his design of the Wright Flyer, but world aeronautics had already passed him by.

The state of the aeronautical art in both Europe and the United States was so swift that the Wrights' companies in Europe found themselves with no market. Production of all manner of aircraft boomed in Europe prior to World War I but remained almost dormant in the United States. "On the eve of World War I (1914), France was reported to have 1,400 airplanes, Germany 1,000, Russia 800, Great Britain 400 and the United States 23." [5]

B. The United States Adopts the British Approach

Federal action, or rather the lack of it, clearly showed that neither the United States military establishment nor Congress was disturbed by having been left by Europe in what amounted to a "technological backwash." [6] However, matters pertaining to aeronautics tended to appear complex to both the administration and to Congress. Dr. Charles D. Walcott, Langley's successor as Secretary of the Smithsonian Institution, along with other aeronautical enthusiasts, some from industry and some from the military, had pressed Congress and the administration for years to take aeronautics under the Federal wing as important to the Nation. Great Britain had established its own solution to determining a Federal role in aeronautics by establishing an Advisory Committee on Aeronautics in 1910. Walcott sought

[4] Kelly, op. cit., p. 145.
[5] Levine, Arthur L. United States Aeronautical Research Policy 1915–1958. Doctoral dissertation, Columbia University. NASA Library, 1963.
[6] Anderson, Frank W., Sr. Orders of Magnitude, A History of NACA and NASA 1915–1976. NASA History Series SP–4403, NASA, 1976.

the same type of body to advise the Federal Government and provide guidance to a national research laboratory.

Walcott and others advanced numerous plans between 1911 and 1915, saw them fail for one reason or another. However, the experience of accumulated failures gave Walcott increasingly sharp skills in the art of lobbying.[7]

He obtained the introduction of a joint resolution based on his earlier Smithsonian memoranda for the advisory committee and national laboratory. Franklin D. Roosevelt, then Assistant Secretary of the Navy and, for this resolution, spokesman for the administration. approved the resolution.

C. NACA is Formed in 1915

Senator Ben Tillman and Congressman Ernest H. Roberts introduced the joint resolution to establish NACA, but despite the favorable committee report and administration support, it appeared that adjournment, scheduled for March 4, 1915, would allow the resolution to die. Congressman Roberts suggested a familiar congressional maneuver to prevent this. There was sufficient time to tie the NACA enabling legislation to the Naval Appropriations Bill as a rider. In this form, the NACA bill was signed by President Wilson on March 3, 1915, with an appropriation of $5,000 for the first year of operation.

Twelve presidentially appointed non-paid members from the Government and the civil scientific community were "to supervise and direct the scientific study of the problems of flight, with a view of their practical solution," and to "direct and conduct research and experiments in aeronautics." All members, even of the later technical subcommittee, served without compensation except for travel expenses.

As a first act, the new National Advisory Committee set about to sum up the state of aeronautics in the United States. This was indeed a brief task. Orville Wright was still improving his Wright Flyer and conducting air shows, but it was clear that flight tecnology has passed him by years earlier. The "industry" consisted of a few handicraft shops, owned by enthusiasts who had either paid the Wright Company a license fee, were in litigation with them, or who had not yet tried to sell an airplane. There was interest and some activity in the military services, the Bureau of Standards and in the Weather Bureau, but coordination was nonexistent. The need for a national laboratory was clearly proven by this survey, emphatically confirming the views which had been advanced by most committee members for years.

However, few in Congress, nor anywhere else, knew of the existence of the Advisory Committee. In fact, during Senate hearings in 1918 on aircraft production, none of the committee were called to testify and one Member who had heard about the Committee spoke of it in the past tense.[8]

The Committee did publish a glossary in which the "aeroplane," for purposes of identification in the United States, became "airplane." The science behind the vehicle, however, remained "aeronautics."

Despite the nearly complete apathy of the Congress toward the goals of the Committee, they had made progress toward their labora-

[7] Levine, op. cit., p. 12.
[8] Kelly, op. cit., p. 49.

tory in incremental, informal steps. It was to be located at Langley Field, outside of Hampton, Virginia.

By the time the administration officially approved the transfer of the land to the NACA (President Wilson, April 24, 1919), the buildings and land preparation were largely completed. Then, formal dedication took place on June 11, 1920, and NACA had its national aeronautics laboratory, the Langley Memorial Aeronautical Laboratory (after Samuel P. Langley).

D. A Philosophy Emerges

An early concern, voiced by Roosevelt when he spoke for Wilson's administration to approve the concept for forming an advisory committee for aeronautics, was that civil interests might evolve to dominate the committee at the expense of Government (military) objectives. He recommended changes in membership which would retain a "controlling interest in the activities of this proposed committee." [9]

Still fresh in Roosevelt's memory was the shock of finding that the United States' own pioneers had demonstrated the first workable powered aircraft to Europe and now, only seven years later, he could claim only a spectator's seat in this international arena. In his endorsement of the Advisory Committee, cited above, Roosevelt observed that the European war tensions had brought on a "great military necessity" which had fostered a "rapid development of aircraft and demonstrated the practical utility of these vessels of the air, and has placed this country far behind in the use of aircraft." [10]

The committee, on the other hand, had always envisioned a far more elementary role. That there would be no effort to aid the military or the civil industry in a game of "catch-up," except as the revelation of fundamental principles, ". . . to increase the safety and effectiveness of aerial locomotion for the purposes of commerce, national defense, and the welfare of man." [11]

The Committee remained firm in their intended scope of effort, repeatedly assuring all that their efforts would be purely scientific and that all construction and operating activities would be "left to the Army and Navy and to individuals." [12]

Coupled to this resolve to remain academic was an equally powerful commitment that no researcher's work should be directed. Requests for research would be considered but assignments, regardless of origin, could not be made. This high degree of autonomy was a source of double irritation to the military. In the early days of the Langley laboratory, the NACA people became such an anathema to the military that a concerted effort was made to make them vacate the premises. In General Billy Mitchell's words: "It is difficult to handle this National Advisory Committee in any way. It (the NACA) does no good here nor any

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[9] Roosevelt, Franklin D. to Padgett, L. P. U.S. Congress. House. Committee on Naval Affairs. Hearings, 63d Cong., 3d sess., Feb. 12, 1915. Washington, D.C., U.S. Government Printing Office, 1267–1268.

[10] Ibid.

[11] "Advisory Committee on the Langley Aerodynamical Laboratory." Smithsonian Miscellaneous Collections, vol. 62, No. 1 (July 17, 1913–14).

[12] Walcott, C.D. to Hawley, Allan R., President of the Aero Club of America, Apr. 7, 1915. Secretary's File, 1909–1924, S.I.A.

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other place that I can see and there is a project of law now for its abolishment which I hope will take place." [13]

NACA Senior Staff Engineer, L.M. Griffith, claimed that at a meeting of the Air Service Officers on June 15, 1920, the "possibility of ousting NACA from the field" was discussed and Col. Hensley "promised to do every thing within his power to bring this about." [14]

Nevertheless, the Langley laboratory survived and continued its efforts to correlate wind tunnel findings with full scale flight tests and to develop the needed tools for aerodynamic study—the nonexistent instrumentation and recording systems which would reveal the relative performance of aerodynamic surfaces as well as flight vehicles under varying flight conditions.

Then, in the mid-1930's the signs of war in Europe again appeared. Reports began to reflect rapid progress in all areas of aeronautics in Europe, primarily in Germany. NACA Chairman, Joseph S. Ames, reported to Congress that United States supremacy in available research facilities was "seriously threatened." [15]

NACA Director of Aeronautical Research, George W. Lewis, after an extensive tour of Germany and Russia in 1936, had found that any claim by the United States of supremacy in aeronautics was optimistic. Charles A. Lindbergh, members of NACA, also toured German aeronautical centers and industrial facilities. His correspondence with Ames was blunt and clearly warned that the United States military air capability was obsolete by German standards. He also confirmed the high productivity of the German industry but warned that new design development at a faster rate was needed, else "Germany continue to be the leading country in the world." [16]

A deep concern over the prospect of United States participation in a war with Germany swept through the military and also through the NACA. In 1936, the joint Army-Navy Aeronautical Board reached the conclusion that in the event of war, NACA should give up its independence and place itself under the direction of the Board. Shortly thereafter, a special NACA subcommittee was convened by Chairman Ames to consider this viewpoint.[17] Their decision was the same as that of the Board with the recommendation that, in a state of war, chairmanship of the NACA should be transferred to the chairman of the Army-Navy Aeronautical Board, General Oscar Westover, who was also Chief of the Army Air Corps.

Lewis visited Europe once again a few months before the outbreak of war in September 1939. His German hosts allowed almost complete freedom of travel. Lewis brought back yet another confirmation of the enormity of the German aeronautical progress, productive capacity, and readiness for war. This information was relayed to Congress by Vannevar Bush, who replaced Joseph S. Ames in 1939 on his retirement. Along with it, Bush made a successful plea to increase the personnel and facilities of the NACA.

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[13] Mitchell, William to Mott, T. B., April 22, 1920. Correspondence 1920, Box 8, Mitchell Papers, National Archives, Washington, D.C.

[14] Griffith, L. M. to Lewis G. W., June 17, 1920. Headquarters Correspondence, 1916–1935, Box 1, RG 225, National Archives, Washington, D.C.

[15] U.S. Congress, House, Committee on Appropriations, Subcommittee on Deficiency Appropriations, Hearings, 74th Cong., 2d sess., 1936, 661–62.

[16] Lindbergh to Ames: November 28, 1938, NASA Historical Archives.

[17] NACA Minutes, October 22, 1936; NACA Executive Committee Minutes, February 11, 1937, NASA Historical Archives.

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A new aeronautics and wind tunnel facility, the Ames (after former Chairman, Joseph S. Ames) Aeronautical Laboratory, was authorized by Congress in 1939. It was located at Moffett Naval Airfield 40 miles south of San Francisco. Construction began on September 14, 1939, a few days following the authorization.

The new aeronautical facilities would be put to heavy use immediately, but they were not enough. Lindbergh had repeatedly warned that aircraft propulsion systems were as obsolete as the United States military aircraft. He urged that a new center, specializing in aircraft engine technology, be established immediately. In June 1940, Congress agreed. A site was made available at the Cleveland, Ohio municipal airport for this center, to be known as the Lewis Flight Propulsion Laboratory.

During the war years, 1941–1945, NACA efforts were almost totally in applied technology. New fighter aircraft began to appear and essential changes to increase their speed, indeed to make them reasonably safe to fly, placed a double and sometimes triple shift of work load on the NACA Centers

Following the war, the NACA returned to a more orderly routine but found an equally great, although quite different, challenge and responsibility. Its own bank of basic research, built up during the 1920's and early 1930's, had been exhausted in the early war years. With peace, the NACA had become heir to large quantities of more advanced German research, not only in aeronautics but also in propulsion and rocketry.

Integrating the German research and pursuing their own, which had been shelved during the war years, produced a decade of progress into flight regimes believed to be impossible by many aerodynacists in the 1930's. Rocket engines permitted the exploration of high-speed subsonic flight, transonic flight and supersonic flight. The rapid development of the jet engine permitted the practical application of this fresh bank of data to revolutionize military aircraft. At the same time, rocketry and the art of missile weaponry was evolving rapidly beyond that of the German V–2. Success with missile development was such that its advocates had begun to question whether or not the manned military aircraft really had a future role.

Von Braun made numerous comments to the effect that he saw the V–2 more as a precursor to a space ship than as a military weapon. Some of his points are made in a 1945 interview at Wright Field.[18] He noted that:

> The whole of the Earth's surface could be continuously observed from such a rocket (in Earth orbit). The crew could be equipped with very powerful telescopes and be able to observe even small objects, such as ships, icebergs, troop movements, construction work, etc. They could also carry out physical and astronomical research on problems which could only be tackled at that altitude, due to absence of the atmosphere.

E. Early Interest in Rocketry

Von Braun's enthusiasm and the large quantity of V–2s and other hardware transported to the United States from Peenemunde deeply

[18] Zwicky, Fritz, "Report on Certain Phases of War Research in Germany," U.S. Air Force, Air Material Command, Wright Field, Dayton, Ohio, 1947, 38–42.

impressed research teams in four military services. However, a conservative stance by their superior officers served to counter enthusiasms. Dr. Vannevar Bush. Director of the Office for Scientific Research and Development (OSRD) expressed disdain for the future of rocketry, even as a long range weapon. He testified before the Senate Committee on Atomic Energy in December, 1945: [19]

> There has been a great deal said about a 3.000 mile (4,828 km) high-angle rocket. In my opinion such a thing is impossible and will be impossible for many years. The people who have been writing these things that annoy me have been talking about a 3,000 mile (4,828 km) high-angle rocket shot from one continent to another carrying an atomic bomb, and so directed as to be a precise weapon which would land on a certain target such as this city. I say technically I don't think anybody in the world knows how to do such a thing and I feel confident it will not be done for a very long period of time to come. I think we can leave that out of our thinking. I wish the American public would leave that out of their thinking.

The OSRD was combined with the Joint New Weapons and Equipment Board (JNWEB) and became the Joint Research and Development Board (JRDB). However Vannevar Bush remained as Chairman of this new review board, the function of which was to "coordinate all research and development activities of joint interest to the War and Navy Departments, so that the War and Navy Departments will establish and carry out a strong, unified, integrated and complete research and development program in the field of national defense." [20]

His influence, or rather, the position of the Board at this time, was adequate to prevent any unification of interests or joint project for orbital developments between the various interested groups which could be found in the Army Ordnance Corps, the Navy Bureau of Aeronautics (Bu/Aer), the Naval Research Laboratory and the Army Air Forces.

1. The Army Ordnance Corps

This group was responsible for "Operation Paperclip," the rescue and salvage mission which resulted in the transfer of Wernher von Braun and other distinguished German scientists, along with their stock of V–2s and other hardware from Peenemunde to the United States in May 1945. From 1945 until 1949, the German team from Peenemunde and the Ordance Corps assembled, studied and launched the stock of V–2 rockets from White Sands, New Mexico carrying aloft a wide assortment of scientific payloads. Although the V–2 was the world's most technically advanced rocket during this time, it was certainly no space ship—only a short range ballistic missile. The early interest of the Ordance Corps in satellites had faded and in 1949, Dr. Von Braun and his group were moved from the Army Ordnance Proving Ground at White Sands to the Redstone Arsenal, Huntsville, Alabama. At Redstone, they were to develop a new rocket which would become an IRBM (Intermediate Range Ballistic Missile).

2. Naval Research Laboratory (NRL)

A review of the technical feasibility of a satellite led to the NRL conclusion that project would be too large in scope for them at that time.

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[19] U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Preparedness Investigation. 85th Congress. 1st and 2d sessions. November 1957, January 1958.
[20] Charter of the Joint Research and Development Board. Secretaries of War and the Navy. June 6, 1946. amended July 3, 1946.

The decision was made to concentrate on upper atmospheric research, using sounding rockets.

3. The Navy Bureau of Aeronautics (Bu/Aer)

Studies of the German rocket program by Bu/Aer were conducted during 1943 and 1944, culminating with the formation of a Committee for Evaluating the Feasibility of Space Rocketry (CEFSR) on October 3, 1945. Its ultimate objective was the launch of instrumented satellites for the purpose of learning the characteristics of the spaceflight environment.

In a sense, the CEFSR was a focal point within Bu/Aer for several hardware projects applicable to advanced rocketry and spaceflight. These projects included the rocket motor development of Aerojet in which hydrogen and oxygen were blended and burned as fuel for the first time.

By the end of October, 1945, the CEFSR submitted its proposed satellite launching program to Bu/Aer. Bu/Aer responded by awarding feasibility study contracts to Guggenheim Aeronautical Laboratory and to Aerojet. Although the results of those studies favored and confirmed the original CEFSR satellite feasibility analysis, the projected cost estimate of the program, set to fall between $5 million and $7 million, was completely beyond anything the Navy would consider.

CEFSR then made a concerted effort to gain support from the Army Air Force for a joint project to develop their single-stage-to-orbit vehicle designated the "High Altitude Test Vehicle" (HATV). The Air Force indicated some encouraging interest but finally turned down the opportunity. The history of the CEFSR effort drew to a close after two additional studies, one by another Bu/Aer group under Abraham Hyatt and another jointly contracted to Aerojet and Glen L. Martin Co., confirmed again the feasibility of the design.

4. The Army Air Force

The Air Force had an interest in satellites but preferred to examine the project of launching one independently rather than as a joint venture with the Navy. They turned to the Project Rand [21] group at Douglas Aircraft.

On May 12, 1946 Project Rand produced their answer, a report entitled "Preliminary Design of an Experimental World-Circling Spaceship." It would demonstrate to the War Department that should the issue of space weapons development arise in the future, the Air Force was at least as prepared for the responsibility as the Navy.

Where advanced technology is concerned, there is sometimes an advantage to being second. The RAND scientists were familiar with the Navy's simple, oxygen-hydrogen HATV. It was a high risk package. Their own approach was to achieve the same performance with proven

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[21] Project RAND was established in late 1945 and initially operated as a semiautonomous branch of the Douglas Aircraft Corporation, responsible directly to the Vice President, Engineering. Qualified physicists, engineers, and mathematical analysts were drawn from Douglas and other aircraft firms, and assembled at Santa Monica in separate quarters. The original concept was that several companies would get together and set up an advisory type function which, in turn, would allow RAND to advise the various services on what they should procure, so that the services would not request the "impossible" from industry in the area of aircraft armaments. In November 1948, the RAND Corporation was created and became a completely autonomous non-profit research institution.

technology to the extent this was possible. They based their "World-Circling Spaceship on V–2 fuels and technology but added multi-staging. This would more than compensate for their less powerful fuels, reduce the technical gamble and place a 500 lb satellite in a 300 mile orbit within a 5 year period—or by 1951.

The Rand report, perhaps anticipatory of the military judgment that a 500 lb satellite was too small to be considered a potential weapon of destruction, included a number of eloquent and some prophetic justification for its construction.[22]

For example:

A satellite vehicle with appropriate instrumentation can be expected to be one of the most potent scientific tools of the Twentieth Century.

The achievement of a satellite craft by the United States would inflame the imagination of mankind, and would probably produce repercussions in the world comparable to the explosion of the atomic bomb . . .

To visualize the impact on the world, one can imagine the consternation and admiration that would be felt here if the United States were to discover suddenly, that some other nation had already put up a successful satellite.

The Rand report also offered these observations:

1. The booster to launch a satellite is the same as a booster to launch a destructive missile over intercontinental distances.
2. The existence of this technology places the future of manned aircraft operating as bombers or observation platforms in question.
3. The satellite can replace the aircraft as an observation platform.
4. The satellite can also serve as a weather forecasting device and a communications link.

Twelve years later, the 1946 Rand observations were repeated by others during the Senate's 1958 inquiry into the status of the space effort in the United States.[23]

Senator Lyndon Johnson noted that the Sputnik ". . . demonstrates beyond question that the Soviet Union has the propulsive force to hurl a missile from one continent to another." During that year, 1958, General Gavin added his voice [24] to observe:

> The ICBM is the consequence of manned bomber obsolescence . . . not the cause. The manned bomber will become obsolete when effective [armed] surface-to-air missiles can be employed against it . . . as soon as they are on site in numbers.
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> If manned bombers cannot penetrate enemy territory [in the future] then certainly manned observation aircraft cannot. Observation must be provided by an unmanned reconnaissance vehicle . . . for a short-range missile it will be a recoverable drone operated by remote control; for an ICBM it will, in time, be a satellite.

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[22] Project Rand: "Preliminary Design of an Experimental World-Circling Spaceship," Santa Monica, May 1946.

[23] U.S. Congress. Senate. Committee on Armed Services. Subcommittee in Preparedness Investigation. Hearings. "Inquiry into Satellite and Missile Programs," Part 3. 85th Congress. 1st and 2d sessions. Feb. 26, Apr. 3, and July 24, 1958. 2428.

[24] Gavin, General James. "War and Peace in the Space Age," Harper, New York, 1958. 11.

However, in the climate of 1946, no satellite project, joint or otherwise, was to be authorized. There was interest but there was a problem—no clear cut military mission. Another review, completed in March 1948, by The Technical Evaluation Group of the Committee on Guided Missiles, for the Joint Research and Development Board, made similarly negative conclusions, but again suggesting that the studies continue.

F. The First Satellite Plan—1948

The military services underwent a major reorganization with the passage of the National Security Act of 1947. The three services were given equal status in the new Department of Defense. Its first secretary, James Forrestal, in his "First Annual Report of the Secretary of Defense" made a startling announcement in late 1948.

> The Earth Satellite Vehicle Program, which was being carried out independently by each military service was assigned to the Committee on Guided Missiles for coordination. To provide an integrated program with resultant elimination of duplication, the committee recommended that current efforts in this field be limited to studies and component designs; well-defined areas of such research have been allocated to each of three military departments.[25]

This was the first public announcement that the United States was giving any thought to an Earth Satellite. Reactions in the United States were negative—ranging from charges of squandering the taxpayers' money to stronger concerns that the program was an unholy defiance of God's will.[26]

The Russians joined the negative chorus and soundly condemned the program. The Soviet journal "New Times" referred to the "madman Forrestal's idea of an Earth Satellite . . . an instrument of blackmail." [27]

No further official mention of a satellite or satellite program was to appear in the open literature of the Government until November 1954. At this time a press release approved by Secretary of Defense Charles Wilson contained a brief comment that studies continue on the Earth Satellite Vehicle Program. Interestingly, at a press conference preceding this release, the Secretary commented that he was not aware of an American satellite program.[28]

G. Project Mouse (Minimum Orbital Satellite of the Earth)

As studies within the Government continued, interest in an Earth satellite began to spread in the civil sector. Widespread attention to the potential of the space domain resulted from three issues of Collier's Magazine in 1952. Colorful and imaginative illustrations illuminated short essays on space by Werhner von Braun, Fred L. Whipple, Heinz Habber, Willy Ley and others. A subsequent Walt Disney film de-

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[25] Forrestal, James: "First Annual Report of the Secretary of Defense," Department of Defense, Washington, D.C., 1948, p. 129.
[26] Green, M. C., Lomask, M., "Vanguard—A History," NASA, SP 4202, Washington, D.C., 1970, 9.
[27] U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, "Soviet Space Program: Organization, Plans, Goals and International Implications," Staff Report May 31, 1962, 57.
[28] Hall, R. Cargill, "Early U.S. Satellite Proposals," Technology and Culture, Vol. IV, Number 4, Fall, 1963, 428.

picting a Lunar flight and showing astronauts manuevering weightless in space, fanned additional interest.

It was also during this period a correspondence began between Werhner von Braun and S. Fred Singer, physicist, University of Maryland. Subsequently Singer was to contribute his imaginative and insightful thoughts at many of the satellite planning sessions, both within and outside of the Government. In 1953 at the Fourth Congress of the International Astronautics Federation, Singer proposed a Minimum Orbital Unmanned Satellite of the Earth (MOUSE). It was based on a 1951 study by the British Interplanetary Society.

Singer's plan was seriously reviewed by The Upper Atmosphere Rocket Research Panel at White Sands in April 1954. In May, Singer presented his plan again, this time to the Hayden Planetarium's Fourth Space Travel Symposium. Thus the public and a growing number of scientists were becoming aware that artificial satellites had outgrown science fiction and were now a feasible part of the real world.

H. The International Geophysical Year (IGY)

The largest military rocket boosters, staged with smaller rockets could place a light payload in orbit, as numerous feasibility studies by Bu/Aer, Rand and others had shown. As mentioned earlier, military support for a small orbiter program was not available in the early 1950's because there was no clear military application. However, there were a growing number of scientific uses for even a small instrumented satellite, and there was a growing interest in launching one. By the early 1950's, the problem was no longer "can it be done" but "how does one go about getting Government support (the launchers and facilities) for a costly program of initially, purely scientific values?" According to Green and Lomask,[29] a group of scientists devised an ingenious and ultimately successful solution. At a gathering at the home of James Van Allen in Silver Spring, Maryland in 1950, which included Fred Singer, J. Wallace Joyce, a Bu/Aer geophysicist, Ernest H. Vestine, geophysicist, Carnegie Institution, Sydney Chapman, an eminent British geophysicist and Lloyd Berkner, head of the Brookhaven National Laboratory, Berkner proposed that another "Polar Year" be established.

The first Polar Year, in 1882, had set the precedent for international cooperation and participation in a scientific project of mutual interest. The focal point would be one or more instrumented satellites capable of observations and measurements of the Earth and atmosphere not otherwise possible. European scientists subscribed to the plan and in 1952 the International Council of Scientific Unions appointed a committee to make the arrangements. It was to last for 18 months instead of 12 and since its effort was to be directed at the entire Earth, the name was changed to the International Geophysical Year (IGY), and would include 67 nations.[30]

The originally established interval of a Polar Year to occur each 50 years was changed to 25 years. The second (and final) Polar Year

[29] Green and Lomask, op. cit. p. 20.
[30] Catalog of Data in the World Data Centers, Vol. 35 of Annals of the International Geophysical Year, Pergamon Press, New York, 1964, vi.

was 1932. Adding 25 years would set the date 1957 for the start of the new IGY, an ideal time because it would coincide with the period of maximum solar activity.

As the planning for the IGY advanced, a goal setting and coordinating group was established, known as *Comite Special de l'Anee Geophysique Internationale* (CSAGI). Lloyd V. Berkner, who could be considered the "inventor" of the IGY, became vice president of CSAGI.

The establishment of an IGY would bring together outstanding scientists of many nations with their myriad of interests. It would not automatically bring approval that orbiting satellites would be its centerpiece. The two major steps in accomplishing that end would be to gain the approval of CSAGI first, then seek governmental support to finance the venture.

By the time of the October 1954 CSAGI meeting in Rome, Russia had joined the IGY. The Russian capability with rockets and their interest in space was known. A. N. Nesmeyanov of the Soviet Academy of Sciences had said on November 1953 that satellite launchings and moon shots were already feasible. In March 1954, Moscow Radio carried materials designed to excite Soviet youth on their prospects for exploring the solar system. The Moscow Air Club announced their own studies of interplanetary flight.[31]

However, at the CSAGI meeting the Russians remained silent observers and watched CSAGI adopt the American proposal to study the Earth with satellites on October 4th. It read:

> In view of the great importance of observations during extended periods of time of extra-terrestrial radiations and geophysical phenomena in the upper atmosphere, and in view of the advanced state of present rocket techniques, CSAGI recommends that thought be given to the launching of small satellite vehicles, to their scientific instrumentation, and to the new problems associated with satellite experiments, such as power supply, telemetering and orientation of the vehicle.[32]

1. The National Academy of Sciences: IGY Committee

The IGY was scheduled to run from July 1957 through December 1958, far enough into the future, it was thought, to devise a satellite, match it to a launching scheme and gain governmental support for the execution of the plan. In January of 1955 the IGY Committee of the National Academy established a Technical Panel on Rocketry—slightly enlarging the original group who had conceived the scheme for the satellite as well as the IGY to make proper use of it. The panel included Kaplan, Odishaw, Newell, Singer, Spilhaus, Whipple, Van Allen, Nathaniel Gerson, Bernhand Hauwitz from the Academy's Meteorology Panel and Geshardt Schilling of the IGY staff. The Panel created a special study group called the Subcommittee on the Technical Feasibility of a Long Playing Rocket (that is, a satellite). It became known as the "LPR" subcommittee and included William H. Pickering, director of the Jet Propulsion Laboratory (JPL), John W. Townsend, assistant head of the NRL Rocket Sonde Branch and Milton Rosen from the Viking rocket project.

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[31] Green and Lomask, op. cit. p. 23.
[32] Hogan, John D., "The Viking and the Vanguard," Technology and Culture, Vol. 4, no. 4, Fall 1963. 435–437.

The Committee and its "LPR" Subcommittee were to report to the United States National Committee on feasibility, not make actual hardware recommendations. Their report was made on March 9, 1955 and contained no surprises. They saw anyone of the total of these existing options as feasible: a large single stage launcher could be used to place a few small rockets into orbit with little or no instrumentation payload; the three stage launcher could place an instrumented payload in orbit; or the new and larger engine then being developed could power a completely new vehicle capable of carrying a large, well instrumented payload into orbit.

The Committee estimated that any of the three possibilities could be realized within two to three years—placing the launch time within the IGY.

2. The Eisenhower Administration is Approached

The National Academy of Science and the National Science Foundation, even prior to receiving the recommendation of the United States National Committee for the IGY, had begun their role of gaining the support of the Administration.

Following innumerable briefings of various offices directly associated with the White House, President Eisenhower's interest was achieved. The launcher would require an expenditure of equipment, and funds, set aside for purposes of Defense—thus the matter came into the hands of Secretary of Defense Charles Wilson. Wilson was personally disinterested and placed the responsibility for the project with his Assistant Secretary for Research and Development, Donald Quarles, who favored the idea of an IGY satellite.[33]

3. The Stewart Committee

Quarles recognized that there were a number of prospective launchers for which various satellites systems had been proposed with solid feasibility studies to support them. When he found his General Sciences Coordinating Committee favoring the funding of three parallel developments, he appointed an ad hoc "Group on Special Capabilities," generally called the Stewart Committee for its chairman, Homer J. Stewart of JPL.

The group included Charles C. Lauritsen, an eminent physicist and, like Stewart, a professor at Cal Tech. Joseph Kaplan, chairman of the United States National Committee for the IGY, Richard Porter, consultant for Advanced Developments to the General Electric Company's Missile Division, George H. Clement of the RAND corporation, Clifford C. Furnas, Chancellor of the University of Buffalo, J. Barkley Rosser, rocket ballistician and professor of astronomy and head of the McMath Hulbert Observatory at the University of Michigan.[34]

The Stewart Committee made it known almost immediately that they would endorse the IGY satellite launching but would need further study to select the most suitable hardware. This green light allowed a continuation of efforts to pave the way for the program. The numerous Russian statements and internal programs emphasizing space exploration were without doubt a strong asset in obtaining Administration approval.

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[33] Green and Lomask, op. cit. p. 30.
[34] Green and Lomask, op. cit. p. 35.

4. Eisenhower Announces Satellite Plan July 29, 1955

There was a desire to announce the satellite plan before Russia announced its own plan. Eisenhower agreed to announce the plan even prior to the completion of the Stewart Committee deliberations and, through Press Secretary James Hagerty released the following statement on July 29, 1955:

> On behalf of the President, I am now announcing that the President has approved plans by this country for going ahead with the launching of small Earth-circling satellites as part of the United States participation in the International Geophysical Year . . . This program will for the first time in history enable scientists throughout the world to make sustained observations in the regions beyond the earth's atmosphere.
>
> The President expressed personal gratification that the American program will provide scientists of all nations this important and unique opportunity for the advancement of science.

The President's statement was embargoed until the next day, then released along with statements from the Secretary of Defense, the National Academy and the National Science Foundation.

5. Russia Announces Satellite Plan August 3, 1955

A day later, the Moscow press announced that the USSR would also place a satellite into orbit during the IGY. Moreover, according to the August 3, 1955 New York Herald Tribune, a Russian physicist, speaking of the International Astronautics Federal in Copenhagen, declared that the launch would occur in 1957 and would be much larger than anything the United States would attempt.

The United States had been correct in anticipating the Russian announcement and in terms of this race anyway, had a clear victory.

6. Selecting the Launcher (Stewart Committee)

The Stewart Committee made comparisons of three basic systems: The NRL Viking, the Army Redstone and the new Air Force Atlas system. The Atlas could place a minimal payload of 150 lbs. in orbit and with modest growth, could exceed this by hundreds of pounds. While clearly the Atlas was the most attractive, it was also the least available. Any such program could push back in readiness date as a weapons system, and in 1955, this was not a desirable state of affairs. The choice was therefore limited to the first two possibilities, either of which would put something in orbit but neither were satisfactory without some additional development.

The Stewart Committee deliberated in an atmosphere of intense interservice rivalry, and after making a decision favoring the NRL Viking (to become Vanguard), was reconvened by Quarles only to make the same decision a second time. On September 9, 1955 the official announcement favoring the NRL Viking was released by the Deputy Secretary of Defense, Reuben Robertson. All three services were thus notified that the Navy would be in charge of a joint three-service program.

To General Medaris, Von Braun and others at the Army Ballistic Missile Agency in Huntsville, Alabama, the news came as a shocking blow—difficult to believe. They saw the Vanguard project for what it was, a valiant attempt to build a new and relatively limited launcher under the close to ruinous constraints of an unprecedented development schedule and with under financing.

They knew their established track record in guiding the evolution of their rapidly maturing ballistic rockets could make the satellite project a routine extension of existing capability. They could remove much of the risk from the project. Yet, it was to go in the high risk direction. The reason—a conviction on the part of the Administration that the IGY satellite plan was a clear threat to the tightly scheduled ballistic rocket capacity. Although it was to be permitted, it should be conducted to interfere minimally with defense related programs.

7. Viking Progress and Sputnik

The Vanguard project had no periods of smooth progress. It was conducted under an aura of tension—the ever present concern that Russia would achieve the first satellite. All the evidence available weighed heavily in the direction of a Russian victory in this initial lap of the race into space. Yet, it was not a concern that induced cooperation beyond the most reluctant support of those outside of the immediate Vanguard Operations Group (VOG).

A prolonged struggle was required even to gain a launching area at Cape Canaveral. This struggle set the stage for a continuing effort of seemingly endless trials to achieve a viable launcher. Nothing came easily to the Vanguard Operations Group (VOG). Inexperience was the pervasive enemy, not only within the VOG but throughout the network of contractors and subcontractors. Nothing could be taken for granted and the VOG, working at the Cape, routinely served as quality control for all Vanguard components, virtually becoming an extension of the factory of the Glenn L. Martin Co., prime Vanguard contractor.

III. A NEW ERA—THE FLIGHT OF SPUTNIK AND ITS AFTERMATH

A. Sputnik Appears—October 4, 1957

Within the VOG, the concern that Russia would achieve a successful satellite launch before the United States grew deeper each day, adding frustration to the sure knowledge that haste would invite failure. The intense dedication of the VOG brought the reward of early successes as the series of sub-orbital tests were made to prove each successive stage. A successful test of the complete Vanguard launcher was completed (without the payload or orbiter) during October 1957, and the VOG knew that it had achieved orbital capability.

However, during the conduct of these tests on the third Vanguard test Vehicle (T.V.) which was designated TV–2 since the series began with TV–0, Sputnik was successfully launched.

The race to achieve the first artificial satellite was over—a clear Russian victory. But the race was a close one and the VOG, as well as Von Braun's team at the ABMA now wished to demonstrate that the Russian capability was not unique. A close second place might show this, and reduce the psychological impact of the Russian achievement.

The no-priority project which had been Vanguard shifted quite suddenly into the national spotlight. It became the great hope of the entire Nation. The VOG moved from obscurity into a national goldfish bowl,

suddenly under the scrutiny of the Administration, Congress and the public.

1. Sputnik Alarms Congress and the Administration

Within hours after Sputnik appeared, the Senate Preparedness Subcommittee, chaired by Lyndon B. Johnson initiated an inquiry into the status of the Nation's missile and satellite capability.

Eisenhower requested and received a briefing on the progress and prospects of the Vanguard project as well as the satellite launching capability of the ABMA in Huntsville, Alabama. On October 8, 1957 Eisenhower instructed Secretary of Defense, Charles Wilson to have the ABMA prepare its Redstone at once as a back up to the Navy Vanguard. On October 9th, Eisenhower's press secretary, James Hagarty, announced that the United States planned to launch a "satellite-bearing" vehicle in December 1957.

This vehicle was to be the Vanguard Test Vehicle number 4 (TV–3) which was to carry a "test" satellite. A small 2 kilogram (4.4 lbs.) satellite was to be orbited by T–3, without a scientific payload but carrying a radio transmitter. The news release greatly increased the pressure on the VOG, mostly because an enthusiastic press translated the announcement to read that in effect, in December, the United States would have met the Russian challenge. The VOG was still fighting the quality control battle to launch TV–2, a Vanguard with a live lower stage, two dummy upperstages and no payload. TV–2 had been at the Cape since August and had undergone several complete rebuilding sessions as it failed one checkout after another. Finally, TV–2 was successfully launched on October 23, 1957, clearing the way for TV–3, which would have all live stages plus the small test satellite payload.

2. Viking Test Vehicle 3 Explodes December 6, 1957

The test vehicle TV–3 was known from the outset to be an extremely high risk flight. The second stage engine in particular had never been test fired for the full duration of its thrust period. The vehicle was readied for flight, however, and gave much fewer check out problems than TV–2. On December 6, TV–3 was launched, lifted four feet and fell back in flames. Its spectacular failure was witnessed by an international assemblage of reporters and observers, the largest group ever to assemble for the purpose of witnessing a launch.

Newspapers are seldom kind and headlines related the failure to a further blow to national prestige. Senator Lyndon B. Johnson spoke of the failure as "most humiliating." But perhaps the meanest blow of all came with the offer of aid to the American delegates, from the Russian delegation to the United Nations under the Russian plan to provide technical assistance to backward nations.

3. First United States Satellite, Explorer I Orbits February 1, 1958

The VOG began a harsh schedule to ready the TV–3 back up Vanguard designated TV–3 BU. However a long series of technical difficulties delayed the launch giving the ABMA team a chance to launch successfully their own Explorer satellite.

The initial goal, that of putting a sientific payload in orbit during the IGY had been achieved. However the accomplishment did not signal the completion of a goal. Instead it signalled the entry of the

United States in a highly competitive race with Russia to demonstrate a national capability in the mastery of the new domain of space. Subsequent successful launches and failures were experienced by the Vanguard team and the ABMA, as detailed in other sections of this history. However, neither the public, nor Congress nor even the armed services viewed the combined capability of the two teams as an adequate national effort. The exploitation of the new space domain called for a larger and more permanent organizational structure.

B. Groping for a Way to Manage Space Activities

1. The First United States Space Agency

Shortly after Sputnik, Eisenhower had given interim responsibility for the U.S. space program to the Defense Department. In February 1958, Congress authorized Defense to establish the Advanced Research Projects Agency (ARPA). In March, Eisenhower gave his approval to an interim plan for space exploration which had been advanced by ARPA. Thus in a genuine sense, the first U.S. space agency was a military organization, ARPA.

2. The NACA Plan

Although a number of plans for a civil space agency were advanced in Congress, some as bills, the Administration and most legislators favored giving the well established and highly regarded NACA full responsibility, The urgency, still strongly felt in the Federal as well as the private sector, simply would not allow the time needed to start a totally new agency.[35]

NACA leaders firmly convinced of the superiority of their own committee structure, proposed that their board be enlarged to 17 members; their name changed to the "National Advisory Committee for Aeronautics and Astronautics," and their role and responsibility remain one of the research and assistance to "user" agencies and civil groups.

NACA felt confident that the new space flight research responsibility would be assigned to them. In November 1957, the NACA chairman, Lt. General James H. Doolittle, approved the main committee establishment of a new Special Committee on Space Technology to be headed by H. Guyford Stever. Branching down from the new committee, a group of new subcommittees were to be formed each to handle "special aspects" of space challenge.

In their bid for this new role, the main committee had met in January 1958 and on January 16 published a new resolution on space flight.[36]

The resolution was carefully worded but subject to differing interpretations. Statements were included in which the NACA traditional role would be greatly enlarged to include ". . . Design and development of scientific and military space vehicles and their launching, flight and recovery." However, in later paragraphs, responsibility for the various types of vehicles was "resolved" to be the responsibility of the user agencies. The total thrust of the resolution seemed to suggest a view that the space effort on the part of NACA would be the conduct

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[35] Levine, op. cit., p. 151.
[36] U.S. Congress. House. Select Committee on Astronautics and Space Exploration. "The National Space Program" House Report 1758, 85th Congress, 2nd session, May 12, 1958.

and coordination of a larger but parallel program patterned after the successful "X" series of experimental aircraft.

Eisenhower and his advisors, especially his newly appointed Science Advisor, Dr. James R. Killian, acting from the conviction that the new space agency should be a civil, or at least a nonmilitary effort, strongly favored turning the responsibility over to the NACA. However, there was a problem or two. First, the committee structure of the NACA did indeed "report to the President" but it was not obligated to him too closely. During its history the NACA had shown itself to be rather refractory to political leadership. There was a question as to whether or not an issue as politically volatile as the new space venture should be relegated to a rather independent committee.

Secondly, the NACA tradition had established its character as more academic than executive. Research, regardless of the quality and responsiveness to the problems of users, did not seem an adequate substitute for executive action and primary responsibilities.

The skills and facilities of the NACA in aeronautics were without equal in the Nation, but something more was needed.

3. The National Aeronautics and Space Administration (NASA) Emerges From the National Advisory Committee on Aeronautics (NACA)

Early in 1958, Eisenhower asked his science advisor, Dr. James R. Killian, Jr., to formulate a plan leading to an adequate civil space agency. Killian, in conjunction with experts in administrative organization, such as William M. Finn of the Bureau of the Budget, submitted a recommendation to Congress in the form of a draft bill on April 4, 1958.

The latter months of 1957 and early part 1958 was a period of confusion and competition throughout the Congress and in all executive agencies having aspirations to take a role in exploiting the new space domain. Bills proliferated as congressional champions of various agencies sought to secure new scientific and space related functions for a favored agency.

Levine's [37] account of this period puts the evolving NACA plan in context with some of its rivals.

> The leaders of NACA were among those diligently and rapidly working on the preparation of a proposal for the assignment of the space role. Their first step followed the traditional lines of NACA procedure as they established a special committee on space technology, headed by H. Guyford Stever, Associate Dean of Engineering at MIT. This was on November 21, 1957. Less than two months later, the Main Committee of NACA adopted a resolution recommending that the national space program could be most effectively implemented by a cooperative effort of the Department of Defense, the NACA, the National Academy of Sciences, and the National Science Foundation, together with universities, research institutions and industrial firms. Under the NACA plan, the military would be in charge of development, construction and launching of space vehicles, while the NACA would have responsibility for research on satellites and scientific experiments in space.

This was a simple solution for the NACA since it merely elaborated on its existing procedures, contacts and close rapport with the military.

Competition for the proposed NACAA included bills to turn space exploration over to the Atomic Energy Commission, the National

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[37] Levine, op. cit., p. 146.

Science Foundation as well as totally new agencies, one to be called the Commission on Outer Space. Another new entity was proposed in two bills to be called the Department of Science, an umbrella for science, parts of which would cover space.

Even more comprehensive were bills proposing a new Department of Science and Technology which would subsume existing agencies such as the National Science Foundation, the Atomic Energy Commission, the Bureau of Standards and the NACA.

The Department of Defense, being the owner and manager of the Nation's existing space capability was also a rival. In February, 1958, the Defense Department, with the authorization of Congress, created the Advanced Research Projects Agency (ARPA). This organization was brought into being expressly to direct and manage future space exploration. The month following its creation, ARPA received the President's approval to go ahead with its plans for space exploration. Thus ARPA became the Nation's first space agency. However, the ARPA role was transitional. As Levine [38] described it:

> Despite this development, it was clear that the Administration did not intend to give the Defense Department the science space role on a permanent basis. The President was trying to establish an agreement with the Soviets that "outer space should be used only for peaceful purposes." He did not wish to jeopardize this position by designating a military agency as the Nation's chosen space pioneer. Rather he felt that the U.S. scientific space program should be conducted by a civilian agency. In this view he was strongly backed by both his political and science advisors. As a result of this strong Presidential preference, the Defense Department was never really in the running for the science space role, and proposals for giving the space research job to the Defense Department were discarded early in congressional consideration of this matter.

4. The Administration Favors NACA

The Administration's desire to place the responsibility for space in the hands of civilians gave the NACA confidence that it would become the Nation's space agency. However, the NACA structure was such that its operating head was selected by its committee. There would be no single executive in charge of the space effort whose tenure would be in the hands of the President. Under the NACA organizational practices, the President would have only an indirect control over an activity for which he would be responsible. This was not considered an acceptable arrangement, and work was begun on a Bill to establish a new space agency, headed by a single executive and which would absorb the NACA.

NACA leaders disturbed over this initiative, and convinced that their 40 years of operating experience had proven the merit of their committee structure, sought and obtained Congressional support. As summarized by Levine: [39]

> Disturbed by the way the Administration bill was developing, NACA leaders requested friendly Congressmen to introduce measures which would give NACA the space role, while preserving the traditional NACA organizational pattern. As a result, in March and April 1958, bills were introduced by Representative Frelinghuysen (Republican—New Jersey) and Senator Francis Case (Republican—South Dakota) giving the responsibility for outer space development to NACA. Both bills would make slight alterations in the name of the agency, but would leave undisturbed the arrangement whereby the agency would be governed by a 17-man board appointed by the President and a Director appointed by the Board.

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[38] Levine, op. cit., p. 149.
[39] Levine, op. cit., p. 155.

The "NACA bills" were introduced much later than "rival bills" which would give the space role to the AEC, NSF, or to a new department of science. This fact did not help congressional considerations of the point of view of NACA leaders. The NACA viewpoint was dealt a severe blow when on April 2, 1958, President Eisenhower sent a message to Congress proposing the establishment of a new agency, the National Aeronautics and Space Administration, into which NACA would be absorbed, and under which the 17 man board would be down-graded to an advisory status only. Henceforth, as members of the Administration, leaders of the NACA would be obliged publicly to concur with the President's prescription for the organization of the new agency.

After the Administration bill was introduced, on April 14, 1958, it became increasingly clear that the Administration proposed to change not only the organizational structure of the NACA but proposed as well what would really be a new agency, with NACA as its nucleus, rather than an enlargement of the old aeronautical research group. The new agency would not only have a single executive, but it would be a powerful operating agency as well, with significant authority for contracting for the building of "hardware" and for systems development, for launching satellites and other space vehicles, and for transfer of use of other government facilities that could contribute to the space program.

In brief, the Administration bill placed the total responsibility for the civilian space program in the hands of a single agency. The NACA proposal would divide the responsibility among the interested agencies and the military.

IV. PERFECTION AND PASSAGE OF THE NATIONAL AERONAUTICS AND SPACE ACT

A. Congress Examines the Administration Bill

The congressional jurisdiction for space was widely claimed. Hearings had begun in 1957 by a number of committees including the Senate Preparedness Investigating Subcommittee of the Senate Armed Services Committee, both Senate and House Appropriations Committees, the House Armed Services Committee and the Special Subcommittee on Outer Space Propulsion of the Joint Committee on Atomic Energy.

By February 1958, the Senate had established a Special Committee on Space and Astronautics. The House also centralized its interest by creating its Select Committee on Astronautics and Space Exploration.

The two dedicated space committees intensively examined every aspect and ramification of the Administration bill, and, working independently, extensively rewrote it. Many measures they dealt with, such as patents and foreign relations, had little bearing on the scope or organization expressed in the bill. However, other modifications did, such as the structure of the new agency, its power and its relationship with the military. Identification of the major points of departure between the Administration bill and the Congressional Committees, and their resolution was synthesized by Levine as follows: [40]

1. Organizational Structure

The organizational structure proposed by the Administration puzzled many members of both the House and Senate Committees. The Space Board outlined in the Administration bill seemed to these members to be neither fish nor fowl. The Board generally would have advisory powers only, yet it seemed that it might overshadow the Director of the agency in some respects. There was, for example, a requirement that the President must give the Board "a reasonable

[40] Levine, op. cit., p. 165.

opportunity" to recommend nominations for Director of NASA before he appointed a person to that post. Other provisions in the bill required that the Director consult with the Board before he initiated or substantially modified policies or programs, transmitted requests for appropriations to the Bureau of the Budget, established major constituent organizational units of the Agency, assigned major functions, or appointed heads of major constituent units. In addition, the Administration bill provided that the Board would make an annual report to the President, and such other reports as it deems appropriate, and would generally advise the President, as well as the NASA Director.

The composition of the Space Board bothered some members of the Congressional Committees. The Administration bill provided that the Space Board should have seventeen members of which "no more than eight . . . shall be designated from appropriate departments and agencies of the Government of the United States, including at least one who shall be from the Department of Defense." Other members of the Board must be non-governmental and would be appointed because of their eminence in "science, engineering, technology, education, and public affairs, and shall be selected solely on the basis of established records of distinguished achievement."

Two things about the make-up of the proposed Board were disturbing to some House and Senate Committee members. First, non-governmental members would be in the majority by at least 9 to 8. Indeed, the non-government majority could be greater, since the language of the bill made it mandatory that only one Government representative—from the Defense Department—be appointed. The other seven posts, while seemingly reserved for members from the government, could be given to persons from private life without violating the provisions of the bill. Some Congressmen feared that the Board might be dominated by special industrial interests unless provision was made for a clear Governmental majority. The NACA Main Committee, they pointed out, had a Governmental majority from its inception.

The other cause of concern to some of the legislators was a lack of representation from the Defense Department on the Space Board. Military interests and effective liaison by NASA with the services would be neglected unless the Defense Department participation in the Space Board was bolstered, they felt.

As a result of these twin concerns, the House Committee amended the Administration Bill to provide that 9 of the 17 members must be drawn from the Government, and to provide that three of the Space Board members be from the Defense Department.

2. Status of NASA in Executive Branch

Both the Senate and House committees which were studying the Administration bill were concerned that the proposed space board would be ineffective. There would be a lack of executive power. The Senate committee proposed the creation of a high level Space Policy Board, eliminating the Administration's proposed Advisory Board.

Its seven member Space Policy Board, operating from the Executive Office of the President would include the NASA Director, the Chairman of the AEC, as well as the Secretaries of Defense and State. The remaining three members would be designated by the President.

The House committee proposed a more direct, simpler solution. It would greatly increase the authority of the Director and give him direct access to the President.

3. NASA Military Relationship

Both the Senate and House committees saw that the Administration bill left the NASA-military relationship as an informal and flexible arrangement. For example, NASA, should it choose to do so, could limit itself to research and turn all hardware development tasks, including those of a strictly civil nature, to the military.

The Senate committee reacted to this by carefully defining the jurisdiction of NASA and the Department of Defense and placed coordination authority in its proposed Space Policy Board. The House

committee also amended the wording of the Administration's bill and established a military liaison committee which would consist of personnel from the Department of Defense.

4. A Conference Committee Resolves Differences

The creation of a Space Policy Board, appearing in the Senate version but not in the House version was amended to include the President as chairman, an eighth member. Its name became the National Aeronautics and Space Council. It was expected by Congress to be a policymaking and coordinating body of major significance, associating the President himself as a responsible source of policy for the space program.

The military liaison concept of the House version was also retained in a modified but broadened form. Called the Civilian-Military Liaison Committee, it would have an equal membership from NASA and from the military.

The Administration proposal for an Advisory Space Board was stricken from the bill.

The concern of both committees that NASA would have the freedom, should it choose to use it to limit its activities to research and look to the Defense Department for all development and operational pursuits was met by altering the language in the "Declaration of Policy." NASA was given responsibility for aeronautical and space activities except those associated with defense. The word "activities" was substituted for the word "research" which had been used in the Administration version.

The Administrator of NASA was required to be a civilian and was given wide operational powers.

The changes in the Administration bill reflected the concerns of both the House and Senate "space" committees that the broad scale activities to be undertaken by the new NASA; the world wide tracking activity, the development and use of spacecraft—eventually manned exploratory vehicles, would be beyond the capability of an agency structured to be merely an extended NACA. They felt that the NACA, even though it was a respected scientific establishment, lacked the experience to do contracting and managing on the scale expected.

The Report of the House Committee issued in May 1958 illustrates this point: [41]

> No one can question the great contribution NACA has made to United States aviation and to the first phases of space inquiry. Its director, Dr. Dryden, is a scientist of proven ability, as is his staff. They have the advantage of long experience in working with the military. The great majority of scientists questioned have expressed approval of its choice as the nucleus of the new space agency. The nature of the approval, however, and the qualifications expressed, have varied greatly. The Air Force, which has long worked hand in hand with NACA, has been especially emphatic in its praise. Major General Bernard Schriever, in his testimony, saw NACA taking over the space effort with a little greater authority and a broader scope of responsibility. As General Schriever expressed it, the NACA is the perfect "building block" for the new agency.
>
> Other witnesses found NACA, in its present form and tradition, something of a stumbling block as well. Their objections stemmed principally from the apparent official confusion of what NACA is doing, and has been doing, and what

[41] U.S. Congress. House. Select Committee on Astronautics and Space Exploration. "The National Space Program" House Report 1758, 85th Congress, 2nd session, May 12, 1958. 12–14.

the space agency is supposed to do, must in fact do, if the effort is to succeed. NACA, as now constituted, is a research agency, with the traditions of a research agency. It has acted through the years as a sort of extraordinarily valuable problem-solver for the services and for civil aviation. But all of the problems it has solved have been technical. Although NACA is very definitely, as Dr. Dryden put it, an operating organization, its operating traditions have all been consultative, advisory, mediatory.

This points up a considerable problem. It would not be a serious matter, perhaps, that the NACA, as constituted, has no tradition of developing hardware behind it. (Its mode of advance into the space field has also cast some doubt on the reservations of rocket experts who felt that aerodynamics and aeronautics are two separate disciplines.) But the lack of any tradition of direction and coordination could be very serious. This is a problem by itself. Without drastic sweeping changes, it is no mean feat to inculcate a spirit of decision-making in an organization that has lived and thrived on a tradition of peaceful advice-giving. And any space agency, by the urgent nature of its mission, by the inevitable commingling of civilian and military in many fields, will have to know how to rap knuckles.

Also questioned by both the House and Senate Committees was the ability of an extended NACA to deal effectively with the powerful military and industrial groups, each with its special interests. Witnesses from these groups, such as Assistant Secretary of the Navy Garrison Norton, General Schriever, General Putt of the Air Force, and Deputy Defense Secretary Quarles, testified to their lack of concern on this project, and affirmed their high regard for the administrative strength and integrity of the NACA type of structure.

Congressional doubts about how well a NACA type organization would fare in the real world brought about changes in the Administration version as well as a rejection of the NACA recommendations. Congress accepted the idea that the NACA would provide a good technical foundation but its organizational concepts, even as modified by the Administration bill, would not equip NASA for successful pursuit of the space program.

The reconciliation of the House and Senate versions of the NASA bill by the conference committee was a difficult and stormy battle. Nearly a month was required, during which communications between the House and Senate Members ceased on occasion. However, agreement was achieved and the conference version was produced on July 16, 1958. President Eisenhower signed the bill on July 29, 1958.

Thus, an administration for space was established, including mechanisms for adjudicating possible, in fact expected, conflicts between NASA and the Defense Department via the National Aeronautics and Space Council and the President.

V. NASA: 1958–1979

A. Administrators

Although the enabling legislation for NASA was not law until October 1, 1958, activities to convert the NACA into NASA began in March. There was a pressing urgency in Congress to see that the new space agency would have a running start. The selection of an Administrator did not become an area of controversy until July. NACA personnel had assumed that their own Director of Research since 1947, Dr. Hugh L. Dryden, would be appointed. Feelings in Congress were

not as unanimous.[42] Some Congressmen felt that the desired level of vision and aggressiveness would not be found in a veteran career employee. However, Dryden was highly regarded by Congress generally.

On August 1, 1958 during his otherwise very acceptable testimony at the hearings on the "Space Act", Dryden made a derisive comment on Von Braun's proposal to place a manned spacecraft on a Redstone missile for a ballistic flight of a few hundred miles. He quipped that "such a flight has about the same technical value as the circus stunt of shooting a young lady from a cannon." Following a number of quick objections to his remark, he made an unsuccessful effort to explain, then retract his comment. But he had indelibly underlined the label he already carried, that of a conservative albeit respected scientist.

Eisenhower then asked Killian, his science advisor, to locate another candidate. On August 7, Killian, with Eisenhower's approval, asked Thomas Keith Glennan to come to Washington to discuss the position. Eisenhower offered Glennan the position and Glennan accepted.[43]

1. Glennan

Thomas Keith Glennan (August 19, 1958–January 20, 1961) came to NASA from the presidency of Cleveland's Case Institute of Technology, a position he obtained in 1947. Born in 1905, he received a degree in electrical engineering from Yale. Prior to World War II, he worked for the motion picture industry as a sound system specialist. During the war, he headed the Navy's Underwater Sound Laboratories. His tenure at Case included service on numerous Federal and industrial advisory boards among which was a term (1950–1952) as a member of the Atomic Energy Commission.

Glennan's nomination as Administrator along with Dryden's Deputy, were received by the Senate Special Committee on Space and Astronautics on August 9th. Full Senate confirmation came on August 15th. Glennan and Dryden were sworn in at the White House on August 19, 1958.

Glennan's prior history left the question open as to his boldness as a leader and Administrator. The burden of management grew steadily in the early months and become even greater after the passage of the Space Act in October.

NASA's rapid growth and growing diversity led Glennan to seek help in organizing it. He contracted with the Washington office of McKinsey and Co., a management consulting firm, to make an organizational study and model which could be used as a long term guide for structuring the agency.[44]

Meanwhile, Congress and the Nation waited, not too patiently, for some bold moves. Then in July 1959, Glennan took his turn to explain his view of the NASA role to Congress. To their dismay, they heard Glennan say, "Basically we are a research, development and exploration group . . . Now we do not conceive our job as taking us into

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[42] Hirsch, Richard; Trento, Joseph. "The National Aeronautics and Space Administration," Praeger Publishers, New York, N.Y., 1973.
[43] Rosholt, R. L., "An Administrative History of NASA 1958–1963." NASA, Washington, D.C., 1966.
[44] Rosholt., op. cit. p. 42.

operational systems, but perhaps to the prototype . . . but not beyond that . . ." Gibney observed, "This was hardly the sort of big thinking that Congress was quite plainly hoping for. The 1958 space law stated clearly that NASA should direct 'space activities' of the United States except for . . . weapons development." [45]

Glennan, it turned out, shared Dryden's approach to management. He was cautious and methodical—definitely not about to leapfrog his way into space, whatever the state of the Russian program. He settled instead for the less showy but no less vital task of amalgamating the diverse programs, personnel and facilities transferred into NASA with the core group, the NACA. None of these parts and pieces including the NACA had ever functioned before as a fully responsible independent operating agency. Glennan presided over the formation and emergence of an operating, nationally and internationally responsive agency. Glennan's tenure at NASA was therefore a hectic and trying period; a time of organizational evolution; a time of realignment of subgroups and reassignment of personnel; a time of structuring both internal and external relationships. Possibly it was not an appropriate time to add the bold moves into space, the hoped for leap frogging of the Russians accomplishments. Also, such moves may have been technically impossible.

NASA's launch record during the 29 months of Glennan's administration shows only eight successful launches out of 25 attempts. Through this period, the success rate improved steadily reaching 50 percent during 1961.[46] Launch vehicle reliability was the problem, not the failure of satellites to function once placed in orbit.

Glennan's legacy to his successor, James E. Webb, was a large one. NASA had become a capable and functioning agency. Reliability programs, long range planning, executive training were established functions. The coupling of the Nation's industrial and university sectors to NASA goals and requirements had been accomplished. Finally, the general management of NASA had been uncoupled from the work load of the Administrator by creating the post of Associate Administrator.

2. Webb

James Edwin Webb (February 14, 1961—October 7, 1968) was nominated by President Kennedy on January 30, 1961 along with the announcement that Hugh L. Dryden had been asked to remain in his Deputy Administrator's position.

The Senate Space Committee acted immediately, holding hearings on Webb's nomination on February 2, several days prior to their formal notification. Lyndon Johnson favored Webb over a number of outstanding "technical" men. He believed NASA would be best served by a tried and expert administrator.[47]

Born in 1906, Webb received a degree in education from the University of North Carolina and then a law degree from George Washington University and an admission to the bar. His career revealed him to be a dynamo of activity, highly successful and respected in the

[45] Gibney, Frank; Feldman, George. "The Reluctant Space Farers," New American Library, New York, 1965. 79.
[46] Rosholt, op. cit. p. 175.
[47] Rosholt., op. cit. p. 187.

field of aerospace as well as in government. After a seven year term with Sperry-Gyroscope, he served in World War II becoming a major in Marine Corps aviation. From 1946 to 1949, he was Director of the Bureau of the Budget, moving from there to Undersecretary of State for three years. At the time he was nominated for the NASA post, he was a director and officer of Kerr-McGee Oil Industries, a director of McDonnell Aircraft and Chairman of the Municipal Manpower Commission. Webb agreed to withdraw from any firm doing business with NASA.

The Space Committee enthusiastically endorsed him and the Senate confirmed him on February 9, 1961. He was sworn in on February 14. NASA had a new type of leader, an unusual man whose forte was administration but who was grounded in law and whose natural element was high technology and aerospace in particular. Added to this was his well established working rapport with the entire executive branch, his first hand familiarity with the Nation's international relationships and his experienced liaison with congressional leaders.

Webb presided over NASA during its period of maximum growth and maximum capability. As Teague [48] put it, when he heard that Webb was resigning:

> Jim Webb has met the test of great responsibility and the demand of leadership . . . he can leave NASA with a realization that he had established the greatest technological team that the world has ever known—a team well capable of reaching the goals which have been set forth.

For personal reasons, Webb departed from NASA nine months prior to the first lunar landing. He left at a time of high personal standing with both the Administration and Congress, closing an extraordinarily successful eight year tenure.

3. Paine

Thomas O. Paine (March 5, 1969–September 15, 1970) was appointed Acting Administrator of NASA by President Lyndon Johnson a few days after Webb's October 7, 1968 resignation. Following President Nixon's nomination, Paine was confirmed as Administrator on March 5, 1969. Born November 9, 1921, he received a Ph. D. in Physical Metallurgy from Stanford in 1949.

During World War II, he served as a submarine officer in the Pacific and was awarded the commendation medal and submarine combat insignia with stars.

Following the war he held a succession of scientific research positions with the General Electric Company. For the five years prior to accepting the NASA position, he was manager of Tempo, G.E.'s Center for Advanced Studies in Santa Barbara, California.

Much solid work emerged during Paine's tenure at NASA. In aeronautics, the "supercritical" wing entered the flight testing stage and produced dramatic changes in traditional concepts of airfoil and wing design. The new wing section, being quite thick, produced wings with greatly increased internal volume, making possible significant reductions in structural weight. The greater lift generated by the new wing made possible wing area reductions of up to 30 percent.

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[48] Olin (Tiger) Teague, Chairman of the House Committee on Science and Technology.

Reductions in drag were made possible not only because of the more efficient shape but also because of the reduced wing area. But, whatever their importance, achievements in aeronautics were pale indeed compared to the space spectaculars which were to mature during Paine's tenure.

Apollo 11, the first human visit to the Moon was an historic event totally without precedent in man's experience. The event could be observed in real time around the world.

For all its grandeur and promise, the lunar landing was an anti-climax to those whose major concern was victory over Russia in the conquest of space. The event and the landings subsequent to Apollo 11, did not alter the downward trend in the NASA funding—a trend which began prior to Webb's departure.

The highlights of the period were rewards from investments made in the past. NASA had entered a period in which investments for future events were becoming increasingly austere.

The NASA budget had declined rapidly between 1966 and 1970, averaging $500 million per year. The number of people employed on space projects had declined from 420,000 (1966) to 190,000 in 1970.

Paine's administration was characterized by contrast. The world could watch the maturing spectaculars while internally the prime task was to minimize the rising costs of deferrals and the losses from cancellations.

Dr. Paine resigned September 15, 1970 to return to the General Electric Company.

4. Fletcher

Dr. James C. Fletcher (April 27, 1971–May 1, 1977) was sworn in as NASA Administrator in President Nixon's office in April, having received his Senate confirmation on March 11. Born June 5, 1919 in Millburn, New Jersey, Fletcher attended public schools in Flushing and Bayside, New York. He received his undergraduate degree from Columbia University in 1940 and his doctorate from California Institute of Technology in 1948.

Dr. Fletcher came to NASA from the University of Utah, where he had served as President since 1964. Prior to that he had a distinguished career in the aerospace industry. He was Director of Hughes Aircraft Co. Theory and Analysis Laboratory for six years, leaving in 1954 to become Director of Electronics for Ramo-Wooldridge Co. where he served for four years. In 1958, he organized and headed the Space Electronics Corporation. In 1961 Space Electronics merged with Aerojet to form the Space General Corp. where he served as President and later Chairman of the Board, as well as Systems Vice President of Aerojet General Corp. Then in 1964, he accepted the Presidency of the University of Utah.

Fletcher accepted the reins at NASA when public enthusiasm and worldwide awe was still high. Just two months prior to his swearing-in ceremony, Apollo 14 had successfully completed the third manned lunar landing. Apollo 15, which carried the Lunar Roving Vehicle, completed its spectacular success during his third month. This was followed by two more Apollo flights, completing the Apollo program. Along with these came the unmanned visits to Mars in the Mariner

series, the visits to Jupiter in the Pioneer series, the launching and triple visits to Skylab the last of which lasted nearly three months.

The era of space spectaculars for NASA, great enough to entrance the world, began in 1969 with the first Apollo lunar voyages. It was at its peak when Fletcher began his service in 1971 and received a slight boost in 1975 with the Russian-United States Apollo-Soyuz Test Project, a mutual docking of the two spacecraft in which coupled air locks could be opened as a passageway between the ships.

The worldwide enthusiasm over man's first departures from Earth and his first visitations to the newest and certainly the largest of frontiers, was not shared in Congress. The declining budget and shrinking activity in NASA had begun prior to Fletcher's arrival and continued as a trend throughout his tenure.

If Fletcher's administration was distinguished as the longest sustained period of manned and unmanned exploratory adventures in space, it was also significant as the era in which the actual design and construction of a lower cost space transportation system began, the space shuttle.

NASA planners had talked about a type of spacecraft which could be used repeatedly like an airplane from the earliest days of the space program. There was no prior art on which to base such a craft in contrast to the maturing art of building larger and larger rocket powered missiles. During the early days the driving urgency was to achieve space flight and then to meet the goal set by President Kennedy to achieve a lunar landing prior to 1970. The missile origins were therefore expanded through all the families of space boosters finally culminating with the Saturn V which drove the Apollo spacecraft.

During Fletcher's administration the urgency changed directions. While the work done to develop the single use boosters and single use payloads was paying off, NASA saw a dramatic increase in practical space applications covering worldwide communication systems, meteorology, earth resource surveys, scientific stellar and solar observations as well as military surveillance satellites and navigation systems. They also saw these applications favored by Congress over the more spectacular lunar and planetary voyages. If the real value of the new domain of space was to mature, a less costly means of transportation seemed essential. The urgency that seemed always present in NASA therefore shifted toward the development of a varsatile "truck" which could service the areas of space most critically important to the near term future—the near Earth orbits. This reusable space transportation system, called the shuttle, would also serve as a launch platform for the auxilliary boosters used to reach the higher orbits of the synchronous satellites.

Fletcher presided over the culmination of NASA's initial space effort, the era of expendable boosters, and also the planning and start of the transition to reusable space transportation systems. When Fletcher resigned in May of 1977, the first shuttle orbiter was completing the captive phase of its test flights, being carried on the back of a Boeing 747.

5. Frosch

Dr. Robert A. Frosch (June 16, 1977–Present) came to NASA from his position as Associate Director for Applied Oceanography at the

Woods Hole Oceanographic Institution, Cape Cod, Mass., a position he had held since 1975.

For the two years prior to that Dr. Frosch was Assistant Secretary General of the United Nations as well as Assistant Executive Director of the United Nations Environmental Program. Previously, from 1966 to 1973, he served the Government as Assistant Secretary of the Navy for Research and Development.

Frosch's tenure, like the latter part of Fletcher's, has lacked the drama of manned space adventures, but has been ornamented with rich returns from the unmanned planetary probes. The center piece has been the continued development of the shuttle, which made its first free flight, a release from a Boeing 747 and a glide to landing, during his third month in office.

The agency has continued its decline in size and spending power, but has succeeded in protecting the continued development of the shuttle, which is now expected to make its first test flight during 1981.

B. Budget

The appearance of Sputnik in 1957 came as no surprise to the hard working team of United States scientists and technicians striving to prepare a launcher and satellite for the International Geophysicial Year. As detailed earlier in this chapter, Sputnik did not surprise the Army Ballistic Missile Agency either. They were dismayed but knew they were in a race for the first Earth Satellite. However, the rest of the world, along with the United States Congress was stunned.

Any idea that the creation of a satellite for scientific purposes was in accordance with the goals of the IGY was totally eclipsed by a deep concern for national security. Russia appeared to have dramatically achieved a new scientific and military prowess far beyond that of the United States.

The budget appropriations shown in table 3–1 are graphed in figure 3–1. The mood in Congress is clearly illustrated by the rapid rise in funding. Relative buying power through the years is illustrated by the heavier line labeled "Constant Year (1967) Dollars".

TABLE 3-1

NASA BUDGET 1959-1979

FISCAL YEAR	APPROPRIATION	1967 DOLLARS	GNP DEFLATOR* FACTOR
1959	184.3	214.9	0.8575
1960	523.6	598.1	0.8754
1961	964.0	1,086.2	0.8855
1962	1,825.3	2,032.6	0.8980
1963	3,674.1	4,024.2	0.9130
1964	5,100.0	5,505.8	0.9263
1965	5,250.0	5,565.6	0.9433
1966	5,175.0	5,341.1	0.9689
1967	4,968.0	4,968.0	1.000
1968	4,588.9	4,429.4	1.036
1969	3,995.3	3,682.3	1.085
1970	3,749.2	3,274.4	1.145
1971	3,312.6	2,751.3	1.204
1972	3,310.1	2,629.2	1.259
1973	3,407.6	2,593.3	1.314
1974	3,039.7	2,142.1	1.419
1975	3,231.2	2,052.8	1.574
1976	3,551.8	2,099.1	1.692
Transition Quarter	932.2	550.9	
1977	3,819.1	2,130.0	1.793
1978	4,063.7	2,112.1	1.924
1979 (estimate)	4,566.2	2,226.3	2.051

Source: NASA Budget Office

* Deflator factor for 1979 is not based on a full years data and is subject to revision.

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Shortly following the Presidential decision and announcement that the United States would visit the lunar surface, a series of manned orbital flights (Mercury) was achieved. These flights clearly indicated that the Russians' prowess in space was not unique. The United States also possessed the science and ability to launch men into space. In terms of funding, hence congressional concern, the Mercury flights coincided with a more relaxed feeling toward space achievements.

Funding began to decline just prior to the next series of manned orbital flights, the Gemini series. It dropped precipitously during and following the Gemini series and continued to decline during and following the Apollo lunar flights. From 1974 to the present, funding in terms of buying power has remained flat and equal to that received by the agency in 1962, the fourth year of its life.

If funding of an agency is used as a barometer to gauge congressional interest, it would appear that in the six years following Sputnik, there was indeed a space race. However, getting a man on the Moon, the Presidential commitment of 1961, would not appear to be of great congressional interest. Once the earliest orbital flight program drew to a close, interest in Congress waned rapidly and no amount of world acclaim or scientific return could reawaken it.

Then, with the general acceptance of the shuttle as a means of reducing the cost of Earth-oriented payloads and placing them in space, the budget flattened.

Manpower, in terms of total employment (figure 3–2) almost duplicates the shape of the funding curve. Beneath the total employment curve a NASA personnel line has been plotted. (See table 3–2 for the actual numbers.)[40]

[40] NASA data is excepted from NASA Packet Statistics, January 1979, NASA, Washington, D.C. 20546.

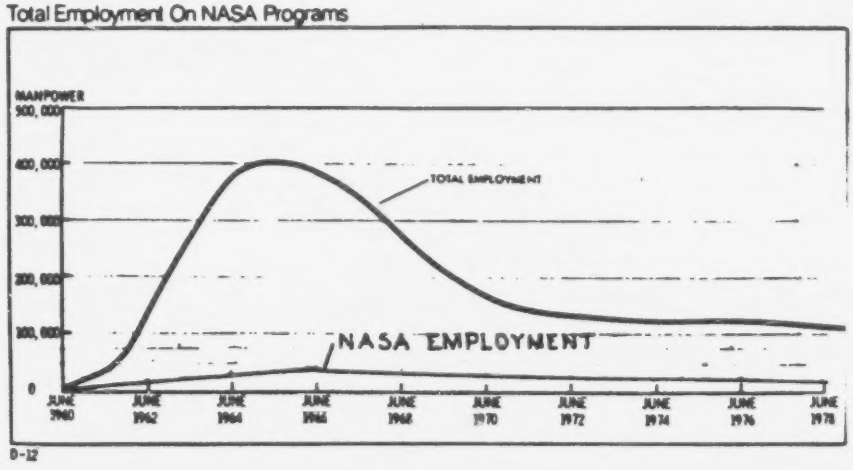

FIGURE 3–2

TABLE 3-2

Personnel Summary

INSTALLATION	Onboard At End of Fiscal Year*										
	FY 1968	FY 1968	FY 1967	FY 1966	FY 1965	FY 1964	FY 1963	FY 1962	FY 1961	FY 1960	FY 1959
NASA Headquarters	2,293	2,310	2,336	2,135	2,135	2,158	2,001	1,477	735	587	492
Ames Research Center	2,117	2,197	2,264	2,310	2,270	2,204	2,116	1,658	1,471	1,421	1,464
Electronics Res. Center	951	950	791	555	250	33b/	25b/	---	---	---	---
Dryden Flt Research Ctr	601	622	642	662	669	619	616	538	447	408	340
Goddard Sp. Flt. Cen.	4,295	4,073	3,997	3,958	3,774	3,675	3,487	2,755	1,599	1,255	398
Kennedy Space Center	3,058	3,044	2,867	2,669	2,464	1,625	1,181	339	---	---	---
Langley Research Cen.	4,087	4,219	4,405	4,485	4,371	4,330	4,220	3,894	3,338	3,203	3,624
Lewus Research Center	4,339	4,583	4,956	8,047	4,897	4,859	4,697	3,800	2,773	2,722	3,809
Johnson Space Center	4,751	4,956	5,407	4,487	4,859	4,277	3,345	1,786	794	In GSFC	---
Marshall Sp. Flt. Center	6,639	6,935	7,602	7,740	7,719	7,679	7,322	6,843	5,948	370	---
Pacific Launch Ops.	---	---	---	d/	21	22	17	---	---	---	---
Space Nuclear Sys. Ofc.	104	108	113	115	116	112	96	39	4	---	---
Western Support Ofc.	---	c/	119	294	377	376	308	136	60	37	---
NASA Pasadena Ofc.	80	79	91	85	376	a/	---	---	---	---	---
Wallops Station	554	565	576	563	554	530	493	421	322	229	171
NASA TOTAL	23,929	34,641	35,860	35,708	34,049	32,499	29,934	23,686	17,471	10,232	9,235

a/ Prior years figures included in WSO. * Includes Temporary Personnel
b/ Figures for North Eastern Office.
c/ Effective in 1968 WSO was disestablished and elements merged with NaPO
d/ Effective in 1966 PLOO activity was emerged with KSC.

TABLE 3-2 Con't

NASA Personnel Summary FY 1970-1978

	Onboard at End of Fiscal Year*						As of 30 Sep 78		
INSTALLATION	FY 1978	FY 1977	FY 1976	FY 1975	FY 1974	FY 1973	FY 1972	FY 1971	FY 1970
NASA Headquarters	1,606	1,619	1,708	1,673	1,734	1,747	1,755	1,894	2,187
Ames Research Center	1,691	1,645	1,724	1,754	1,776	1,740	1,844	1,968	2,033
Dryden Flight Center	514	546	566	544	531	509	539	579	583
Goddard Sp. Fl. Cen.	3,641	3,666	3,808	3,871	3,936	3,852	4,178	4,459	4,487
Kennedy Space Center	2,234	2,270	2,404	2,377	2,408	2,516	2,568	2,704	2,895
Langley Research Center	3,167	3,207	3,407	3,472	3,504	3,389	3,592	3,830	3,970
Lewis Research Center	2,964	3,061	3,168	3,181	3,172	3,368	3,866	4,083	4,240
Johnson Space Center	3,617	3,640	3,796	3,877	3,886	3,896	3,935	4,298	4,539
Marshall Sp. Fl. Center	3,808	4,014	4,336	4,337	4,574	5,287	5,555	6,060	6,325
Space Nuclear Sys. Ofc.	---	---	---	---	---	---	45	89	103
NASA Pasadena Office (NAPO)	---	---	---	35	39	39	40	44	72
Wallops Flight Center	429	426	437	441	447	434	465	497	522
National Space Tech. Lab.	108	94	72	76	---	---	---	---	---
NASA TOTAL	23,779a/	34,188	25,426	25,638	26,007	26,777	28,382	30,506	32,548b/

* Includes Temporary Personnel

a/ Excludes 859 employees in the youth programs.
b/ Includes 592 of ERC which closed 6/30/70.

Employment within NASA peaked at 35,860, coinciding with peaked funding, then declined somewhat more slowly than the funding decline. In 1978, personnel strength matched the 1962 level whereas funding, in terms of buying power matched the 1962 level in 1974, then held constant through 1979.

The labor intensive nature of NASA contracts—the cut and try of development work and the hand built finished products results in the nearly perfect fit of the funding curve and the total employment curve. The comparison of these curves clearly illustrates the extent to which NASA served as a manager to the far larger effort conducted by the private sector. The ratio of NASA employees to those in the private sector was one NASA employee to ten in industry during peak funding. As funding declined, the ratio reached to one to four in 1974 and has remained fairly constant since then, again matching the 1962 personnel strength and NASA employee to private sector employment ratio.

VII. SUMMARY AND CONCLUSION

A. Management Issues

Viewed from the outside, NASA, in its conduct of the space program, gave the impression of a superbly unified management machine. Within a single decade, the largest undertaking in history, the lunar flights, had been started and completed. Satellites of many kinds opened entirely new dimensions in communication and practical studies of earth, its resources and its meteorology. Astronomy, no longer Earth-bound, entered a new era. The staid dignity of this most ancient science was replaced with the high drama of fresh and continuous discovery. The growing uses of the new domain and the advances required to reach and use it represents a common interest, perhaps the only bond between all the nations on Earth. During the second decade, all but a handful of nations became direct participants or partners with other nations in some space related venture.

Viewed from the inside, NASA's management machine was far from unified. While history testifies to the general soundness of NASA decisions, they arose more as final vectors from many internal and often external forces. Some of the salient management issues can be readily identified. They provide a rough overview of the NASA managerial environment.

1. Cooperation of NASA Research Centers—An Issue Solved by Money

Before the signing of the Space Act, both Houses of Congress, among others, expressed serious doubts that the NASA could make the transition from its long history of being a militantly independent, loosely affiliated body of research scientists and consultants to the required highly disciplined, mission oriented body under the control of a responsible executive. Would the NASA centers forego their tradition of autonomy and accept the discipline of executive leadership? That was the big question.

The repetitive appointment of Dr. Hugh Dryden as number two man in NASA, either as Deputy to the Administrator or as Chief

Scientist almost insured a negative answer. It was Dryden's frequently stated belief that executive control would end creativity. Yet without executive control, the Centers would not accept, at least in a timely manner, the congressional intent of gaining access to the space environment to an extent at least equal to that demonstrated by the Russians. Thus the dilemma.

Money was not a restraint during NASA's first eight years and this circumstance led to an elegant and effective solution. The Administrator would subject the Centers of the former NACA to the pressures of cooperation rather than the obedience of executive leadership. There were enough unanswered, yet vital research questions to justify those Centers' operation under a division in NASA to be called the Office of Advanced Research and Technology.

Funds were available to establish new Centers, which would be totally dedicated to the space mission from the outset. These would respond to the two pronged attack on conquering the space environment under two additional executive officers, the Office of Manned Space Flight and the Office of Space Sciences.

If internal conflict, competition for funds, an occasional resignation-in-protest, can be attributed to the vigor and growth of the organization, NASA's solution was a way to the best of both worlds. The powerful research capability of the NACA was preserved. There was no longer a danger that creativity would be squelched nor that the demands and scheduling associated with a mission orientation would usurp the funds or talent of a longer range research effort. The research centers would continue their work in aerodynamics and other fields but would also become assets to the tightly scheduled mission oriented centers.

2. Technology Transfer

The NACA predecessor to NASA had a chronic difficulty in transferring new technological developments into the private sector for practical application. NASA policy has been aggressively to pursue all practical means of rapidly transferring or making available new technology to the public or to potential users. This is done through a variety of periodical publications, press announcement and consulting services.

Although the process of technology transfer is an important activity in NASA, the problem is not the same as it was in the NACA. The greater part of NASA's development work has always been conducted by the private sector under a contract or grant arrangement rather than in a government laboratory as was done by the NACA.

As mentioned in an earlier section, driving NASA's peak years, there were from 10 to 12 people working in NASA projects for every NASA employee. This ratio declined as funding decreased but remains at a 4 to 1 ratio today. Thus, for a major portion of NASA's contribution to advanced technology, the problem of technology transfer was eliminated. It was automatically in the private sector because it was developed there.

Research in aeronautics presents a special case, since a significant portion is still conducted in-house. The great financial risk in aircraft design and production insures a cautious, conservative approach; an

atmosphere in which innovation is seen as a potential threat to survival.

The NACA, almost from the time it was created, sought solutions to transferring its findings into practical application. Theoretical findings, even with wind tunnel testing, seldom aroused the enthusiasm of the industry. Years before the formation of the NASA, the NACA adopted a policy of flight demonstration of innovative aerodynamic design, propulsion systems and demonstrations of new structural and material developments. It was labeled the "proof-of-concept" approach and would bear the high risk of moving a concept from its theory stage into the real world of flight application. With this risk absorbed, the industry could afford to regard innovations in a less fearful way.

The "proof-of-concept" philosophy was continued under NASA and is in effect today. It has been augmented by contract work in which a conventional aircraft is modified and tested by its manufacturer.

Equally important in the technology transfer process is the policy of service available to manufacturers who are developing a new design or who may be modifying an existing aircraft. In addition to consultation, NASA wind tunnels and other research facilities are available to the private sector on a reimbursable basis.

3. Civilian Goals vs. Military

NASA's enabling legislation, the National Aeronautics and Space Act of 1958, expresses the intent that NASA activities should be directed toward peaceful pursuits. Objectives number four and five are explicit on this point:

> (4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
>
> (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere.

The commitment to the pursuit of knowledge and goals for peaceful applications introduced a number of dilemmas, conflicts and continuous requirement for caution in all public statements. For one thing, a bit of new knowledge is usually as valuable to military pursuits as it is to peaceful ones. New knowledge in the aerospace sciences may be of long range interest to peaceful applications but of immediate value to the military. The following elements gave rise to a wide zone of ill defined intent in NASA activities which lay between peaceful and military applications:

> Many primary NACA objectives, e.g. "the improvement of total performance of aerospace vehicles," were carried over as NASA objectives. These same objectives were shared by the military services with whom NACA and now NASA work closely to achieve.
>
> Objective 6 of the "Space Act" requires that NASA share its discoveries with all potential user agencies and identifies specifically those with military significance.
>
> Objective 8 stipulates that research facilities not be duplicated where sharing between agencies is possible. In other words there shall not be wind tunnels for peaceful research and duplicates for military research when sharing would eliminate the need.
>
> The "Space Act" refers to the advanced development of "aeronautical and space" vehicles, but in the definition of these terms, it is broadly defined to include missiles as well as all "related equipment, devices, components and parts."

Finally, the "Space Act" established an agency for peaceful pursuits, to enlarge upon technologies that at the time of the "Space Act" were supported by the military and developed to serve military goals.

However, since the actions of an agency are the final definitions of its policies, NASA's commitment to peaceful pursuits resulted in a number of policies sharply contrasting with the traditional military viewpoint. These are:

A policy of openness to the public and world press on all plans, launches and other activities the exception being to honor the Defense Department classification system.

An active pursuit of international relationships and joint ventures with other nations.

Strong programs to disseminate new advances in science and technology as well as to develop and assist domestic and international groups to become users of satellite weather and resource data.

NASA's close rapport with military aerospace activity, even its extensive use of military and ex-military personnel had no apparent impact on the image of peaceful intent projected by NASA. By the end of NASA's second decade of space activity, all but a handful of the nations of Earth had participated directly, in some fashion, with NASA in a space venture.

B. Conclusion: A Political Synopsis

The development of rocket powered missiles during World War II introduced the technical feasibility that man could reach space. World War II was followed by a continuing concern for national security spurred particularly by an unfriendly distrust of the Soviet Union. Thus the fire of World War II was replaced by a strongly competitive cold war during the 1950's. Under this pressure, the evolution of the military rocket advanced rapidly, and by the mid-1950's the scientific community considered some rocket missile boosters powerful enough to orbit a small scientific payload. However, such an enterprise had no military role at the time and suitable boosters were too costly and too vital to strategic defense for such purposes.

Satellite advocates in the scientific community, recognizing that scientific justification would not obtain a booster, approached the problem as a political one. They invented the International Geophysical Year. This august global scientific congress, with the objective of uncovering knowledge of the planet on a scale beyond the capacity of a single nation, would be a forum, adequate in political prestige, from which the satellite venture could be broached.

A satellite to measure and observe the Earth and the atmosphere from orbit was proposed by the delegates from the United States. The plan worked, and President Eisenhower annouced that such a satellite program would be a contribution of the United States to the I.G.Y.

Although the objectives for the satellite were purely academic, approval for the program had been won on political, not scientific grounds. The Eisenhower announcement gave it political status and marked the point at which the race into space became another objective in the cold war. Although this competitive aspect of the satellite program was recognized by the teams assigned to create the hardware for the program, it was not generally perceived by the Government, Congress, or the public until Russia placed its Sputnik into orbit.

The appearance of Sputnik came as a harsh disappointment to the American satellite teams, as well as to the equally aware among missile development personnel. Within hours of Sputnik's debut, the Administration became aware that it had erred in discounting the effect of a Russian victory in a race to orbit a clearly non-aggressive payload.

To Congress and the Nation, who for the most part were not really cognizant of the academic endeavors of the I.G.Y., of the American satellite program, or of the satellite competition, Sputnik came as an emotional shock, a stunning event with an unascertainable threat value.

Response in Congress was swift. The reaction of the United States to the Russian initiative was like a technological war without weapons. For seven years, funds were made available at the maximum rate they could be used. This rapid growth period has been called a substitute for war by some writers.

Early in this growth period, NASA was committed to a manned lunar landing, the initial phase of which was to test a one man space craft in Earth orbit (Project Mercury).

If funding patterns can be taken as a reflection of congressional mood, one must assume that the successful Mercury flights had a calming effect. By the time the Mercury flights were completed, unmanned missions had become almost routine. The United States had clearly demonstrated that it did not hold a subordinate position in space technology. In terms of funding, it appears that the completion of the initial manned orbital flights ended the urgency initially felt in Congress. NASA funding began a decade of rapid decline, finally leveling off in 1974 (in buying power) when it reached the amount received in 1962.

Congress, it seems, responded forcefully and immediately to what was perceived as a blow to national prestige and security when Sputnik appeared. While the events subsequent to the Mercury flights were a source of continuing awe to the entire world, Congress was not awed. Emphasis instead became centered on satellites which could demonstrate their worth in near term gains, and on projects to reduce space expenditures, such as the shuttle program.

The Winds of Star Wars

James E. Katz

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In 1982, President Reagan proposed a space militarization program that could ultimately cost $18-27 billion. This declaration of intent, and the swirling controversy left in its wake, marks sharply renewed interest by the U.S. policy system in space programs, interest that had waned considerably, especially when contrasted to the period between Sputnik and the lunar landing (1957-1969). This renewed interest casts in bold relief the policy problems that have cropped up during a period of space policy neglect. Interest, however, is concentrated on antisatellite and space antiballistic missile warfare, rather than on across-the-board human use of outer space, even though technology has continued to advance in the latter area. This lag in policymaking presents problems, but also new opportunities, in the space policy field. During its foundation, national space policy was closely studied by the policy analysis community, but it has now been relegated to relative oblivion. Few serious social-scientific analyses of space policy have been published in recent years, and most of those that we do have are written by lawyers in international and space law or by military officers examining strategy and national security. The most recent policy study of NASA, for example, was published in 1975, despite the dramatic changes that have since occurred in its organization.

With occasional exceptions, as with President Reagan's "star wars" speech, space policy over the past fifteen years has been made on an incremental basis by divisions within the Office of Management and Budget (OMB), the Departments of State and Defense, and an isolated group of political appointees at NASA. Space enthusiasts in Congress are few in number, and their ardor is matched only by their ineffectualness. Yet, the post-Apollo disenchantment with the space program should not dampen the interests of policy analysts; this relative neglect of the space program, combined with technological change, has created fertile ground for policy analysis that could influence the social-scientific understanding of space policy and advance the processes involved in its formulation. Like the government, though, academic institutions also blow hot and cold on space policy. Not until the "star wars" speech did public policy analysts launch a flurry of activity.

In a recent speech commemorating NASA's twenty-fifth anniversary, Reagan suggested that it was time for NASA to get out of the way and let private enterprise astound the world with what it could accomplish in space applications. This suggestion, in keeping with other as-yet-unrealized suggestions by the administration for privatizing civil space activities, left NASA officials uncertain about their agency's long-term prospects. The bleak outlook is in marked contrast to NASA's spectacular rise to success culminating in the 1969 lunar landing. During its ascent, NASA was strongly supported by the public, the news media, Congress, and the president. This policy "movement" was successful in harnessing a technology to the betterment of national prestige. But NASA's rise has been followed by an equally rapid descent. As some policy analysts have suggested, when public support catapults a program to prominence, that program can just as quickly fall into a state of neglect, disappear altogether, or become the object of censure. After the Apollo mission, when NASA had no new meaningful goal to take its place, the agency suffered from problems of morale and the departure of superior personnel as tightening budgets and the lack of direction deflated organizational *esprit*. The temporary end of manned missions had a widely depressive effect.

Further along the chain of decline, the lack of public support and funding disrupted the network of university laboratories and training grants for space studies as well as the flow of newly trained space scientists. Aerospace contractors have also suffered, with many smaller firms having gone out of business; this in turn reduces the political support that can be marshaled from the private sector for a program in space.

NASA's supporters responded to this state of neglect by pursuing two major strategies. The first was the Apollo Applications Program and a manned orbiting laboratory, both of which met with public indifference, reduced as they were by budget-conscious presidential staffs and congressional leaders. This may illustrate a

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Catch 22 in the space policy situation: incremental policy produces modest programs, and these fail to attract the political support necessary for growth. The second strategy was to create imaginative and dramatic goals that would mobilize public and political support for an ambitious space program. In 1969, a White House–level task force, strongly influenced by NASA, recommended a gigantic program involving a moon base and manned Mars missions. Public skepticism about the legitimacy of space exploration and the cost of such a program kept the proposal from going anywhere.

President Nixon, nevertheless, did approve the space shuttle plan on a greatly reduced scale; otherwise, the lack of a significant project would have meant the imminent dissolution of the space program. These launchings have excited public support, but the program is lagging far behind schedule. Further, since the shuttle is absorbing money that could otherwise be spent on planetary and space research, it has become a target not only for NASA's critics but for disaffected groups within the agency. President Carter, although urged to fill the space policy vacuum by setting and supporting NASA goals, went no further than to issue a lackluster policy paper in 1978 which made no commitments. President Reagan's enthusiasm for civilian space programs has not been reflected in increased financial support; indeed, NASA budgets have been pared even more than under the Carter administration. Moreover, owing to the current administration's free enterprise ethos, much of the civilian space program periodically seems in danger of being turned over to private firms.

According to opinion polls, Americans believe that a superabundance of capital has already been invested in space exploration, especially in the apparently "wasted" effort of reaching the moon. Some critics have blamed NASA's public relations department for the agency's inability to generate popular support for the space program, not realizing that there are limits to the extent that public opinion can be manipulated by a single group. NASA's decline is the result of many external factors beyond the influence of a public relations department. The space program originated in the Cold War and was sustained by Cold War rationales. Concerns over national security and international competition placed the space issue beyond the manipulation of any one agency. Moreover, much of the early civilian space program was assisted by developments in military programs; the same knowledge needed to develop an ICBM force was also needed for the early space program. Today this kind of overlap is much reduced.

Though competition with the USSR over space exploration reached a low point in 1975 with the Apollo-Soyuz docking, some predict that technological progress and concern over Soviet aggressiveness will create a new climate of rivalry capable of motivating another ambitious space program. But it seems clear that the emphasis in such a U.S.-USSR competition will more likely be on military than on civilian programs.

NASA's current "identity crisis," owing to the lack of a meaningful program and political support, illustrates a kind of reverse technological obsolescence: that of a technology evolving beyond the political and social systems that manage it, instead of falling behind society's demands and uses for it. Technical capabilities in space have outpaced the ability of the nation to pay for them and of the political system to create and define purposes for them. In sum, the external competitive impetus for the original space program, the subsequent incrementally based policymaking system which precludes bold initiatives, and the changed focus for competition with the Soviets seem to have left NASA without a mobilizing purpose.

Satellites and Antisatellites

Space has become a central pivot of our national defense system. About 70 percent of U.S. military communications are transmitted by satellite. Satellites scrutinize ground activity, such as military installations, radar, and telecommunications; they monitor compliance with arms-limitation treaties and can make on-site inspections unnecessary. While the 1967 Outer Space Treaty banned weapons of mass destruction from space, other military activities have continued, with the focus shifting from "dropping atomic bombs" from satellites to combat between space vehicles, as in the current "star wars" scenario.

The reliance on satellites by both superpowers has made the ability to neutralize them or to launch attacks from them a crucial defense issue. President Reagan recently called for a bold effort to protect America through space-based weaponry—partly because of his fear of Soviet advances in space technology and partly because of American dependence on a vital and highly vulnerable satellite system. If U.S. guidance satellites are destroyed—and the threat to military satellites is no longer hypothetical—our 700 submarine-launched ballistic missiles become debilitated. The Soviet Union has been conducting hunter-killer tests for the past fifteen years and appears to have a quick-reaction killer-satellite system that can rendezvous with and destroy U.S. spacecraft in less than twenty-four hours. U.S. satellites have become this vulnerable as a result of policies and nonpolicies of the aerospace establishment. Because of the front-end cost effectiveness of satellites, many missions have been assigned to them without either calculating the cost of long-term vulnerability or creating alternative or redundant systems. Plans are under way to phase out the expendable booster, which will leave the United States with only three to five shuttles to get large objects (satellites) into outer space—shuttles, moreover, which are easy targets for antisatellites (ASATs). U.S. ASAT technology has been held back by the optimistic assumption that the Soviets will not take the next step in the space-war race, as well as by ever-present budgetary limitations.

The Soviets' pursuit of ASAT technology has now, however, motivated the United States to push its own program. The primary ASAT system being developed is a warhead-tipped missile fired from an F-15 operating at high altitude. The missile can neutralize a reconnaissance or other satellite in orbit, but it cannot intercept a Soviet ASAT (because the ASAT's orbit cannot be calculated precisely enough). Lasers, operating at the speed of light, may solve this problem; indeed, the Defense Department has spent about $1.5 billion to develop lasers that can destroy planes and some types of missiles. While the potential of the particle-beam weapon is largely unknown, proponents claim the Soviets are building just such an ASAT weapon system to knock out incoming ICBMs. The Defense Department is also trying to reduce the vulnerability of satellites by means of passive defense.

It is theorized that a "cold war" satellite arms race would result in an automated battlefield, involving only robots and remotely guided satellites, thus sparing earth from a nuclear Armageddon. Others argue that an initial conflict in space would be only the prelude to an expanded war on earth. So far, U.S. attempts to establish a treaty prohibiting ASAT weapons have failed. But it now seems that increased ASAT R&D by the Americans and the possibility that the United States might overtake the Soviet advantage in ASATs within five years have made the Soviets more receptive to such a treaty.

One disturbing aspect of the increasing ASAT activity is its potential effect on the fragile but vital deterrent created by each superpower's ability to obliterate the other. A sophisticated ASAT system, with its large military advantage, could destroy that balance, leading to a major escalation of the arms race and spreading it farther into outer space. The increase in ASAT testing is an alarming development not prohibited by international law or agreement, and it is obviously leading to a frantic technology race. A treaty banning all weapons from space, ASAT testing in particular, would seem justifiable. Yet, complete neutralization of space, as some have recommended, seems unfeasible. The technologies involved often serve peaceful uses, as well as military, and can be readily switched from one to the other. Furthermore, many military uses of space add to mutual deterrence capability, thus strengthening world security and stability.

As more nations attain launch capability, they too must be included in agreements designed to preserve space peace. Thus far, however, U.S.-Soviet negotiations have excluded all other countries. France has proposed an international satellite-monitoring agency; Italy has suggested a UN-sponsored multilateral discussion on disarmament and outer space. The nations of the world each have their own perceptions and fears about the space arms race, and these need to be taken into account when devising international space agreements.

Remote-sensing technology began in the 1800s when cameras in balloons photographed the earth by remote control. Today, the Landsat series and military satellites belonging to the United States and other countries are constantly scanning the globe, both on the visible and the invisible segments of the electromagnetic spectrum. These satellites can detect objects as small as 1 inch, temperature variations of .02 of a degree, trace amounts of minerals and chemicals, and a wide range of the electromagnetic spectrum (e.g., radioactivity, radar, and electronic communications). This technology has been compared to the microscope in its potential revolutionary impact. It permits the survey of pollution emissions, plant disease, building conditions, troop strength and deployments, armaments, ship and aircraft dispositions, and weapon or missile testing. Clearly, there are profound implications for environmental quality, allocation and conservation of natural resources, and surveying human and cultural resources.

This powerful tool has understandably engendered international contention; remote data-gathering presents economic, legal, political, and security threats. Satellites can provide economically useful data on such details as crop conditions, the location of ore deposits, and factory construction. Foreknowledge of agricultural conditions and thus of commodity prices, for instance, can improve a nation's economic viability in the world market when that nation is heavily dependent on sales of certain agricultural products. Satellite-generated data can also affect negotiations for a contract to explore or exploit a country's natural resource. Several nations, including Argentina and Brazil, assert that unrestricted sensing of territorial resources violates the sovereignty of their national wealth and resources, as protected by UN General Assembly resolutions. They define "national wealth" to include *information* about such wealth.

Freedom of Information?

The United States opposes this position, maintaining that the UN Charter, Article 19, advocates the right of all to "seek, receive and impart information and ideas through any media and regardless of frontiers." Washington has sought to reduce opposition to its practice of comprehensive surveillance by giving any individual, entity, or state—including those with differing political philosophies, such as the Soviet Union and the People's Republic of China—complete access to all data gathered by the Landsat series upon payment of a nominal fee. But the U.S. position is weakened by numerous domestic and international treaties and court decisions that give nations the right to control or prohibit photography in their airspace or into their territory. No definition of "airspace," however, is universally accepted. Some nations would extend the term to include the area of Landsat orbits.

There is also opposition to the use of satellite-generated data within the United States. Although U.S. courts have consistently maintained that information is a protected property right, the government consistently ex-

propriates this nonphysical, but still exchangeable, form of property through satellite sensing. No one has litigated on this particular issue, but a legal proceeding has been initiated on the basis of evidence gathered by satellites. Water-borne pollution detected by Landsat has resulted in a court battle over violation of pollution laws. The potential for future legal cases related to satellite-generated data encompasses zoning laws, personal privacy, criminal conduct, and industrial espionage. The legal and constitutional issues of privacy, evidence, and data gathering that result from remote sensing have only begun to be studied. Looming on the horizon are satellite threats to civil liberties. This is not so farfetched as it might seem; during the Vietnam War, satellites were used to monitor antiwar demonstrations.

Many nations tightly control even innocuous information, perceiving its discovery as a needless threat to their stability and security. Other countries' sensitivity to military data gathering can be explained by the fact that satellites can read such details as license plates and uniform insignia. While nations attempt to baffle satellite reconnaissance with various disguise techniques, remote sensing is still the cornerstone upon which strategic arms limitation rests, for it permits the monitoring of treaty compliance.

The use of geostationary orbits is another controversial area. Such orbits (corridors, at about 35,800 kilometers over the earth's equator, where satellites can be placed to maintain a constant position relative to earth) make ideal parking places for satellites in constant contact with a particular ground station. The geostationary orbits over the United States and Canada are already congested, and with increasing demand for telecommunications, broadcasting, meterological, and (possibly) power transmissions, competition for them is intensifying even more.

The United States argues that space can be freely used by all nations without discrimination, if the purpose is for the "benefit and in the interests" of all countries, but it does not wish to limit the definition of "benefit." Eight equatorial countries (Colombia, Brazil, Congo, Ecuador, Indonesia, Kenya, Uganda, and Zaire) have claimed the segment of the geostationary orbit above their national territory as their sovereign domain, formalizing this claim in the Bogotá Declaration. The declaration, then, seems to contravene the 1967 Outer Space Treaty (upholding free exploration and use of outer space) by making foreign occupation of a nation's geostationary segment tantamount to appropriation. The Bogotá signatories defend their position on the basis of equity, rather than international law. They maintain that, under current practice, only the least desirable locations and frequencies will be left for those countries with the most modest financial and technological resources, and that the 1967 treaty, if applied to geostationary orbits, does not carry out its drafters' intention, which was that space development benefit all nations in order to achieve a more just international order.

The exploitation of space has not followed any rationally developed plan but has evolved gradually. No nation has asked permission before orbiting a satellite, and no official protests were heard until Colombia's in 1975. Thus, a commercial satellite operator in the United States has recently placed one of its satellites in geostationary orbit several years before its service will be needed in order to prevent someone else from taking the space. In 1979, Western Hemisphere nations met to seek equitable distribution of the five available satellite spaces, only to discover that the United States was already occupying four of them.

No specific plan effectively addresses the current dispute, which is now in limbo because the equatorial nations cannot remove or interfere with already stationed satellites. If they should attempt to enforce their claims, action against terrestrial targets (e.g., an embargo or property seizure) is a possibility. The United States should develop policy for dealing with such contingencies.

Added to the controversy over positioning of satellites is a controversy over communications per se. For political, cultural, and economic reasons, some countries want to monitor programs broadcast into citizens' homes, including "cultural" programming that may be distasteful, contain unwelcome information, or invite invidious comparison. Even "open societies" may resist direct broadcasting by satellite, fearing that their national culture might be submerged.

The United States and some other nations maintain that the flow of information should be subject to minimal regulation, such as prior notification and consultation, but not to regulation that would inhibit future technological development and the free exchange of ideas and information. The USSR advocates prior consent, controlled program content, and the prevention of illegal broadcasts. Argentina adds even more restrictions, including a right of reply as well as proscriptions against any telecommunication that threatens the security of the state or family or that "impairs the rights of families or individuals, or is contrary to public law or morality."

Three policy issues are at sake in the direct-broadcasting-from-satellites issue: the free flow of information; recognition of the value of cultural diversity; and a nation's right to determine the character of the television services available to its people. The resolution of one can mean further controversy and bitterness over the other two.

Exploiting Space

Less-developed countries want to be able to share in nonterrestrial resources, which they feel are the common heritage of all mankind. The technologically advanced countries argue that this attitude would destroy the commercial incentive to exploit the resources of space. Debate over international policies for such space enterprises as moon or asteroid mining centers around the same concerns as these which dominated the Law of the Sea negotiations on sea-floor mining.

Argentina was the first country to propose a treaty on the use of the moon. That treaty—emphasizing exclusively peaceful uses of space, mandating that any resource development promote higher living standards and socioeconomic progress on earth (especially in developing countries), and prohibiting weapons of mass destruction, weapons tests, military installations, and maneuvers—was at first ignored. The general feeling was that the 1967 Outer Space Treaty dealt adequately with the moon and other celestial bodies. But over time the proposed treaty gathered support and was finally passed by the UN General Assembly. Although the United States signed the treaty, during the Carter administration, the Senate refused to ratify it and the Reagan administration quickly withdrew it from further Senate consideration.

The treaty is now moribund. Natural resources and the international regime necessary to regulate their exploitation are the main areas of disagreement. The United States favors development and rational management of the moon's natural resources, expansion of opportunities for the exploitation and use of those resources, and equitable sharing of benefits derived from those resources—all of which are included in the treaty—but the treaty does not define "equitable sharing of benefits."

Some fear that the international-authority model devised to control seabed mining (and which effectively prevents it) will be used to control the exploitation of celestial resources. Some U.S. policy communities do not believe that an international regime would blunt lunar exploitation as the sea authority has marine mining. They further argue that, in any event, such an international regime is necessary only when exploitation of space resources becomes feasible—which may be years away, or never. In the meantime, arrangements can be made for rational experimentation with various organizational approaches in order to develop effective procedures. While the United States feels it has committed itself only to working on the establishment of an international regime, not necessarily to participating in one, some legal authorities say that the treaty makes submission to an international regime a prerequisite to resource exploitation.

Opponents of the treaty believe that it will prevent space settlement and exploration and that it will slow, if not halt, both the development of space technology and the exploitation of vital resources that would elevate world living standards. Some even believe that it constitutes a fundamental abrogation of civil rights. One section of the treaty allows any government to inspect a space station in orbit around any celestial body except earth; a government would not need permission to board and search such a space station. The U.S. Congress believes the treaty may have the same effect as the Law of the Sea; i.e., through international sharing-and-control provisions, extinguish corporate interest in exploitation.

The growth in space technology has prompted a search for institutional arrangements which can guide space exploration and exploitation. The numerous conflicts described above suggest that the current international infrastructure is inadequate for outer space. Because technology has developed more rapidly than social institutions, nations are having a difficult time agreeing about the fair and efficient allocation of resources. Thus far, there have been two basic approaches to the problem. One, the "national authority" approach, involves nation-states assuming responsibility and authority for the allocation of resources and, where possible, sovereign control of those resources. The other, "functional eclecticism," calls for the incremental growth of international authority and results in an ungainly mixture giving specialized functions (e.g., telecommunications) to particular institutions (e.g., INTELSAT) while leaving complex, but more general, issues (e.g., allocation of geosynchronous satellite "parking places") unresolved.

One possible institutional solution would be to develop a powerful "outer space projects agency" with an international membership. Such an agency could gradually internationalize capabilities for gathering and assessing information derived from remote sensing and about outer space, leading to a fuller sharing of such information. It could also push for intensive international consultations to resolve contending interests and to develop a wider range of policy choices for the international community. Finally, a space projects agency might limit nationally oriented (i.e., self-interested) activity in outer space by enforcing binding reciprocal obligations that would lead to a mutual accountability network. That such an organization will ever be formed, however, is decidedly remote.

This overview of emerging space policy problems has intentionally shifted across many different areas to show the abundance of issues of concern to policy analysts. This survey reveals a rich quarry for those interested in bureaucratic politics, decisionmaking models, organizational processes in constrained environments, links between public opinion and public policy, links between international and domestic policy, societal development, and even futurology. Moreover, the general neglect of the space policy area has reduced the cacophony of "common sense" rhetoric from politicians and ideologues, leaving a zone relatively free of politics and entrenched interests into which social scientists can venture, armed only with their analyses and theories. But this zone will not long remain tranquil. The "winds of star wars" have begun to blow. As their velocity increases, social scientists will have less and less opportunity to make a difference in policy formulation. □

James E. Katz, now with the Lyndon Baines Johnson School of Public Affairs at the University of Texas-Austin, previously taught in the Department of Sociology at the George Mason University, Fairfax, Virginia. He is the author of Nuclear Energy in Developing Countries: An Analysis of Decisionmaking.

Military Uses and Implications of Space

Thomas Blau and Daniel Gouré

Today, U.S. strategic policy remains committed to deterring nuclear war through the threat of punitive retaliation against potential attack. Yet, in light of the enormous nuclear arsenals of both the United States and the Soviet Union, this strategy increasingly places the United States at risk and reduces the credibility of the retaliatory threat. Concerns for escalation control, worried allies, and growing Soviet third-strike retaliatory capabilities have limited the use of strategic power except under the most extreme circumstances (e.g., defense of the United States against a Soviet attack). Long-standing U.S. security guarantees to its allies, for example, increasingly appear incredible both to them and to Americans.

Despite arms control and other areas of coincidental interest, relations between the United States and the USSR are still defined mainly by the shape of the military balance. Whereas the active use of military force for political purposes and in defense of national interests shows no sign of decreasing throughout the world, avoidance of direct conflict, particularly nuclear war, will continue to be central to superpower relations and to the policies of the two blocs. However, superpower nuclear-war avoidance does not negate the political utility of military capabilities. Thus, a military "balance" that both favors the Soviet Union and inhibits U.S. flexibility and initiative conflicts with the global character of U.S. national interests.

It is, therefore, not surprising that the United States is experiencing profound uncertainty over the character and purposes of its military power. Driving the uncertainty is a growing sense of national and personal insecurity over the inability of the United States, either alone or with other countries, to achieve a stable strategic balance. Such a balance was pursued in the 1970s when the United States acquiesced in the Soviet drive for strategic equality. At that point, the Soviets were to have accepted a roughly equal deterrence and to have joined the United States in a search for additional stability in the superpower relationship. This has not happened.

Both the Reagan administration and the anti-nuclear-freeze movement see the present situation as dangerous and potentially unstable. The main responses to this situation have tended, at least lately, to be either increasingly complex and hard to understand (such as the late "dense pack" plan for basing new U.S. intercontinental ballistic missiles) or drastically simple given real-world problems (such as unilateral disarmament). At the very least, then, profound political issues are raised by changing the U.S. strategic deterrent and its underlying policies.

The U.S. deterrent, in many key respects unchanged since the mid-1960s, now faces vastly more threatening forces on the other side. Until recently, suggestions for restructuring or upgrading U.S. strategic forces focused almost completely on strategic offensive forces. In part, this reflected the dominance of offensive thinking and of coercive deterrence embodied in the doctrine of mutual assured destruction (MAD), which viewed the notion of defense as ineffective if not actually destabilizing. This view was codified in the 1972 Anti-Ballistic Missile (ABM) Treaty, the centerpiece of the Strategic Arms Limitation Talks (SALT). This treaty not only banned existing strategic defensive systems but also effectively prohibited deployment of future, more effective ones.

U.S. strategic forces have been shaped by marginal improvements to existing systems and by the effort to draw the Soviets into arms control measures. There has not been much effort to respond to Soviet buildups with fundamentally new or different U.S. capabilities or to address the broad, long-term viability of the U.S. strategic deterrent, now threatened by hard-target, counterforce goals in Soviet buildups. The problem with counterforce is that it implies a destabilizing interest in a first-strike.

For some, such as key figures in the Reagan administration who did not believe that deterrence was automatic and inevitable in the new strategic imbalance, there was a need to negate additional Soviet advantage, to close what the president called the "window of vulnerability."

Simply adding to U.S. offensive forces, however would at some point increase the frustration and the moral question of peacekeeping through the threat of mass annihilation.

It is understandable, then, that the Reagan administration would try to rethink U.S. strategy. The president's "star wars" speech on March 23, 1983, may someday be seen as a milestone in that effort. The administration is now studying the potential military applications of outer space, giving special attention to the possible deployment of strategic defenses in space. The press reports that these studies will recommend to the president an accelerated five-year research and-development program costing $18-27 billion, possibly to deploy strategic defensive weapons in space as early as the year 2000.

Such a move would shift the military, political, and moral basis of deterrence. There is, therefore, a clear need to understand the military uses of space as well as the political and strategic implications of deploying weapons in space. More broadly, the idea of building defenses against nuclear weapons, while not new, again raises old issues: What are the United States' national security objectives? How should U.S. forces be configured and employed in the attainment of those objectives? How stable will such a future world be?

While the Reagan administration emphasizes the primacy of deterring the USSR, others, such as Herbert Scoville, Richard Garwing, and Paul Warnke, see primacy in the arms control negotiation process. They tend to reject options that involve newer, larger, or more elaborate U.S. defense planning or that mitigate U.S. vulnerability in the balance of terror.

The American interest lies in the increasingly questionable strategic balance, the current use of space for military applications, and the considerable lead taken by the Soviets to use space for military purposes. Outer space is now critical to military command, control, and communications (C^3), warning, reconnaissance, and arms control verification, among other functions. If one side's satellites devoted to these tasks were destroyed, it could be rendered "blind, deaf, and mute." It is, therefore, especially sobering that the Soviets have conducted a score of satellite-killer (ASAT) tests; the United States, none.

It is conceivable that the USSR may be able to combine military leadership both in advanced space applications and across the range of traditional capabilities, thus producing grave *political* problems, at least. Space forces, for example, might offer an aggressor the chance to destroy the critical space-based warning and C^3 assets of the defender. For the defender (i.e., the United States), however, space may be critical to frustrating any potential Soviet planning for central war. Even a limited ability to defend the United States or its military assets could provide disproportionately large deterrent benefits, if only by complicating all the decisions made by a would-be aggressor in planning his attack. Because of the enormous burden of calculated coordination that a nuclear attacker faces, confidence reduction—especially in the early moments, when the attacker must deal with warning and C^3 assets—may well critically blunt the edge of a potential first-strike and thereby deter it.

Amendment Required

If space applications can undermine the utility of the potential aggressor's superior forces, then popular perspectives on space require amendment. Those notions are, *first*, that space is an arena for peaceful scientific and humanistic development, in which military activity is neither desirable nor feasible and is subject to being banned in any event; *second*, that space can only passively supplement routine, terrestrial political-military concerns (e.g., arms control verification); and, *third*, that in the extreme, space can be no more than an arena of localized military operations between ASATs, target satellites, and perhaps defensive satellites (DSATs).

To assume that space is militarily useless can turn out to be a "self-fulfilling contradiction" if someone else should establish a visible breakthrough. The impact then may be all the greater because of the gulf between the initial passive, skeptical view of the military use of space and the results exploited by the other side. Surprise will result in shock (a central concept in Soviet military planning).

The military uses of space occupy three levels, which correspond to the current, medium, and long terms:

- There is an immediate need to support earth-based activities and military forces from space, including early warning of attack, C^3, navigation, intelligence gathering, weather monitoring, and even direct U.S.-Soviet communications via the "hotline." Most of these functions relate not to nuclear war but to the day-to-day, peacetime operation of U.S. military forces, the verification of arms control agreements, and the surveillance of global military activities.
- The prospect of combat in space is raised by the impending deployment of workable antisatellite weapons, which will threaten many current support satellites. This is a medium-term issue.
- Space might also be utilized to defend the United States and its allies from the growing threat posed by Soviet strategic and theater-nuclear forces. In the long term—after the year 2000?—a space-based defense against missile attack is possible.

The United States, its allies, and the Soviet Union are now critically dependent on space for the performance of a large number of national-security-related functions. Space-based sensor systems provide early warning of ballistic missile attacks. To provide global strategic and tactical communications, the United States maintains the Defense Satellite Communications System (DSCS), the Fleet and Air Force Satellite Communications Systems (FLATSATCOM and AFSATCOM, respectively), the NATO Communications Satellite System, and the Satel-

lite Data System (SDS). The Soviet Molniya system provides Moscow with a similar capability.

Both the United States and the Soviet Union depend on a variety of satellite-based sensors for purposes of surveillance, reconnaissance, and strategic targeting. Such systems employ a wide variety of sensing systems, including photographic, infrared, radar, and electromagnetic. While the United States is believed to be ahead in high-resolution photographic and image-sensing systems, the Soviet Union possesses several unique systems—in particular, its radar and electronic oceans-surveillance systems (ROARSAT and EORSAT, respectively). It has recently been reported that the Soviet ROARSAT system is capable of providing "real-time targeting" of U.S. warships for Soviet cruise missiles. This means that the Soviets can engage U.S. ships at extremely long range (up to 300 km.), outside their air-defense envelope and without requiring a nearby ship or plane to provide in-flight target tracking.

In addition, there are meteorological and navigational systems which provide information necessary both for accurate strategic targeting and for the operation of conventional and naval forces. The U.S. NAVSTAR Global Positioning System, based on a planned constellation of twenty-four satellites (eight are now deployed), will provide accurate (within 30 m.) time-of-arrival for position location anywhere on earth. The Soviets intend to deploy a similar system.

Satellite surveillance systems help maintain superpower peace, verify arms control agreements, and guard against nuclear proliferation. In 1978, President Carter noted that "national technical means of verification," central to enforcement of the strategic arms control agreements, relied heavily upon satellite systems. Their ability to provide reliable data on a potential adversary's state of military preparedness has allowed powers to limit their own military plans accordingly.

Central to the further exploitation of space, whether for military or civil purposes, has been the ability to place and to maintain men and machines in space. The U.S. space shuttle makes it possible to place 65,000 pounds of payload in low earth orbit (1,000 mi. above earth). This will enable the United States to orbit larger, more complex satellites. Additionally, the shuttle could be used to support construction of a permanent station in space. The Soviet Union appears to be on the verge of creating just such a permanent station.

Space-based systems have for many years served as a force multiplier, enhancing the effectiveness of more conventional military force. However, it is the likely deployment of active weapons, as distinct from the current passive systems in space, that promises to alter radically the nature of war and military planning.

Currently, there are no weapons in space, and their future deployment may be limited by a series of treaties. The 1967 Outer Space Treaty bans all nuclear weapons in space, on the moon, and on other celestial bodies. The 1972 ABM treaty also bans the deployment in space of systems capable of attacking ballistic missiles. The United Nations has proclaimed space to be a "zone of peace." No treaty, though, prohibits the passage of nuclear-armed missiles through space. Nor does any treaty directly prohibit the deployment of ground-based antisatellite weapon systems, such as those currently possessed by the USSR and under development by the United States. While some have argued that international law views space as a place where war is banned, this zone is increasingly indispensable to terrestrial military planning and force posturing.

While some argue that international law views space as a zone where war is banned, this zone is increasingly indispensable to terrestrial military planning and force posturing.

U.S. satellites are increasingly threatened by the Soviet ASAT system, the only one now operational. It was recently tested as part of a nationwide military exercise involving nuclear strikes on U.S. military forces as well as employment of the Soviet ballistic missile defense (BMD) system against U.S. forces. The Soviet ASAT is a large conventional or nuclear-armed satellite launched by a version of the SS-9 ICBM into a co-orbital intercept with the target satellite. The present-generation Soviet system would be effective only against satellites in low earth orbit, although use of a larger booster could allow the system, particularly if armed with a nuclear warhead, to attack U.S. communications and early-warning systems in geosynchronous orbit (22,500 mi.) by means of electromagnetic pulse. Such a capability has long been sought by the Soviet Union in its pursuit of the means for successful nuclear-warfighting.

The United States is taking a number of steps to improve the survivability of its satellite systems against attacks in space or on the ground. An announced $18-billion satellite-survivability program will provide protection for vulnerable earth stations and communications facilities as well as for the satellites themselves. Some systems, such as defense communications satellites, have "silent spares" already in orbit which can be used to replace operational systems. Other avenues of protection include the development of a rapid-reconstitution capability, hardening of satellites against shock or nuclear effects, and enhanced ability to maneuver out of harm's way. In addition, the United States is currently developing a comprehensive threat-management and

surveillance system to track all U.S. satellites and to warn of an impending attack.

Moreover, the United States has sought to develop a countervailing threat to Soviet ASATs. The U.S. system will consist of a miniature homing vehicle (MHV) mounted on a two-stage rocket and carried on an F-15 or similar aircraft. Launched in the air, it will home in on Soviet satellites and destroy them by direct impact. Although the U.S. system will not reach the high altitudes of the larger Soviet rockets, its flexible launch mode will permit its use against low-orbit satellites from virtually any spot on the globe.

The growth in the military and civil uses of space has created a gray area of systems and functions having both military and nonmilitary application. The U.S. space shuttle will transport military as well as civilian payloads, and the Soviets have repeatedly insisted that the shuttle can be used to "capture" satellites. Space stations can likewise be used for a variety of purposes. The Soviet Salyut space station may well be intended as a military observation post and a base for Soviet ASAT weapons.

These early-generation space systems are the forerunners of a broad array of potential support and active military capabilities in space. Advanced infrared technology and mosaic-array sensors may provide the basis for detecting ballistic as well as air-breathing threats from space. One such system, currently being tested under the name Teal Ruby, may serve as the space-based sensor component of a large air-defense capability. Advanced concepts in BMD include use of a mosaic-array sensor overlay which, when launched into the path of an incoming ballistic missile attack, discriminates targets for a ground-based anti-ballistic-missile defense. Other proposed U.S. systems include laser satellites for communicating with submerged submarines; radar satellites, similar to one now operated by the Soviet Union, for ocean surveillance; and improved photographic and sensor satellites for intelligence gathering, submarine tracking, and arms control verification.

Breaking Out of the Future

Even more revolutionary is the prospect of placing BMD as well as ASAT weapons in space. If a defensive system could be put into space, ballistic missiles might be intercepted in the boost phase, prior to separation of the warheads from the missile itself, thus simplifying the defensive problem.

In 1972, it was argued that banning BMD made sense because the technology was rather primitive and unproven and because the attacker could always develop means to counter any defense. Since both sides were believed to be focusing on deterrence, by means of a capability for assured destruction of soft targets (i.e., cities), additional weapons would serve no purpose; they would be "overkill." Defenses for cities, it was argued, would have to be 100 percent effective in order to preclude catastrophic damage, so no defense appeared feasible. However, the possibility of placing a BMD system in space, either alone or in concert with other defenses in a layered effect, invites reexamination of that argument, especially if one's goal is less ambitious than guaranteeing the safety of cities; namely, to preserve some of one's ICBMs in the event of a first-strike.

Ballistic missile defense, in or out of space, now draws interest for a number of reasons. First, even a marginally effective ability to increase an aggressor's uncertainty by complicating his military planning would buttress deterrence. Second, such defenses reduce the potential for catastrophe from an accidental launch, or from a small or third-party nuclear attack. If it could defend itself against such attacks, the United States would not have to respond to limited attacks by retaliation against the USSR. Also, strategic defenses against missiles reduce the plausibility of preemption and cheap victory—again, increasing stability.

The U.S. government is now spending almost $500 million on the development of directed-energy weapons, and soon this figure may well climb to several billion dollars.

Strategic defenses may make sense precisely because they can provide a plausible middle ground between unilateral disarmament, on the one hand, and a continual buildup of offensive forces, on the other. BMD could be the foundation for a panoply of national defense capabilities, including cruise missiles and submarine-launched missiles for a measure of defense against jet aircraft. A defensive posture could provide a practical method of reducing both the likelihood and the consequences of war.

A wide range of technologies are currently being investigated for use in space. Some involve the use of near-term technology in the form of MHVs, pellet charges, or other devices intended to be launched on warning of attack and designed to use the kinetic energy from direct impact with the target. One proposal that has received public attention is the High Frontier concept, whereby existing technologies would be used to deploy a fleet of more than 450 satellites armed with multiple homing rockets for a global BMD. This system is distinctive in that it combines available technology with space-basing. High Frontier advocates insist that their system can be deployed within a few years and at relatively low cost. Their critics disagree sharply.

Potentially far more dramatic would be the deployment of directed-energy weapons—lasers, charged particle beams, and X rays—which can pass easily through empty space. A congressional study has suggested that

"the potential of high-energy laser technology for altering the strategic balance between the U.S. and the USSR is presently unique." Likewise, a report by the General Accounting Office has recommended that the Defense Department speed up the development and deployment of "a constellation of laser battle stations in space" in order to blunt a Soviet strategic attack. Orbiting in space, a directed-energy BMD system could blunt the cutting edge of a Soviet attack as well as defend U.S. satellites from Soviet ASATs.

The United States may be able to deploy a rather simple, low-power laser weapon within ten years. Such a system probably would not be able to serve in a ballistic missile defense role but could defend U.S. satellites against ASAT attack. More-sophisticated systems could be developed within fifteen or twenty years—able to attack not only ballistic missiles but aircraft and even low-flying cruise missiles. One proposal under study is to deploy X-ray lasers powered by a nuclear explosion. In the event of an attack such satellites would detonate themselves, sending out beams of X rays at approaching missiles. Unlike laser satellites, such a system would not need to carry large fuel supplies.

The potential multiple applications of directed-energy technologies make them especially interesting. Such systems could also help protect U.S. warships against attacks from aircraft or cruise missiles and could provide national air defense. Clearly, positioning such weapons in space would give them a range and coverage capability denied to any ground-based weapon.

No one has yet tried to deploy an array of armed satellites. Merely procuring and launching them would be a very costly and complicated enterprise. Estimates of the costs go as high as $300 billion, the likely figure being in the $50-100 billion range. Additionally, directed-energy weapons require extremely high pointing-accuracy, exact target trackers, and very high power output if they are to be used against ballistic missiles. Such technologies are only in the development stage. Currently, the U.S. government is spending almost $500 million on the development of directed-energy weapons, and if supporters have their way this figure will soon climb to several billion dollars.

The "awesome" potential (as a U.S. government study put it) of new space-based technologies is prompting a gradual readjustment of military doctrine and strategy with respect to space-based systems. In September 1982, the Air Force created a Space Command to exercise consolidated control over the vast array of Air Force space programs. Much as the development of the Strategic Air Command presaged a fundamental shift in U.S. strategy and doctrine, so the advent of Space Command suggests an attempt to coordinate U.S. operations in space.

The real innovation of President Reagan's March 1983 "star wars" speech lies not in his suggestion that a new ballistic missile defense might successfully repel attack, but in his call to "break out of a future that relies solely upon offensive retaliation for our security." The core of the president's vision was to ask, "What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack; that we could intercept and destroy strategic ballistic missiles before they could reach our own soil or that of our allies?" Perhaps, then, the determining factor in America's military exploitation of space will be a change in U.S. strategic policy and its objectives—most notably, a movement away from strategies of mutual assured destruction (SALT, Carter), nuclear-warfighting (early Reagan), and unilateral disarmament and toward survivability.

A minimum aim of U.S. strategy under pressure from the comprehensive Soviet buildup, then, should be to buttress the strategic deterrent by increasing the uncertainty of Soviet planners about the probable success—by any standard—of an attack on the United States. Conversely, the Soviet aim implied by ASAT experiments and by Moscow's drive for superiority is to increase their certainty of success should they choose to attack. Ironically, supporters of MAD would oppose U.S. attempts to lower U.S. vulnerabilities—arguing that this might increase the likelihood of nuclear war.

Is there a chance of avoiding military competition in space by negotiating a demilitarization there? The first step toward this goal could be a treaty banning or freezing the development and deployment of ASATs that threaten critical military-support satellites. Further agreements might specify permitted and prohibited military functions in space. Problems, such as the degree of Soviet interest, compliance, and good faith in such an agreement, however, would continue to be very serious.

The opportunities for both military advantage and mutual stability arising from the exploitation of space suggest that the possibility of maintaining space as a "demilitarized" area has already been denied. The threat of hostile action against key U.S. satellite support systems is potentially great enough to mandate a response, if only to maintain the currently precarious strategic balance. More important, strategic defenses become increasingly seductive in light of the Soviet capability to employ force and to neutralize U.S. reaction at almost every potential level of conflict. Only strategic defenses seem to offer the prospect of moving away from the political and strategic precipice represented by assured destruction. Only by deploying defensive capabilities, moreover, can the United States begin to ensure its own survival in a nuclear conflict. Space is a promising medium for such a deployment.□

Thomas Blau, a partner at Decision Directions, has been a consultant on outer space issues with U.S. government agencies.

Daniel Goure has been a consultant to the U.S. Department of Defense on space policy. He has written extensively on strategic defense, Soviet military affairs, and weapons in space.

America's International Space Activities

Marcia S. Smith

The U.S. space program has been international in character since its inception. The 1958 National Aeronautics and Space Act, which created NASA, states that space activities of the United States shall be conducted so as to contribute materially to cooperation with other nations, both in work done pursuant to the act and in the peaceful application of the results of such activities. Directives by President Carter in 1978 and President Reagan in 1982 reiterated this policy, although the Reagan directive added that international space activities shall be pursued if they provide "scientific, political, economic, and national security benefits."

The Reagan language illustrates the many facets of international space cooperation. Initially, the international component of NASA's program was pursued for two reasons: first, because of a genuine desire to involve other countries in exploring the new frontier of space; second, because NASA required worldwide tracking locations and wanted to generate a climate in which other countries would be predisposed to allow tracking sites on their territory. Later, as national budgets became more constrained, the economic benefits of cooperation also became important. Programs that were too expensive for the NASA budget could still be pursued if another country or group of countries were willing to provide some of the instruments, or even entire spacecraft. Similarly, by offering free launch and tracking and data acquisition services, U.S. scientists might be invited to fly instruments on a foreign satillite or at least to receive data. More recently, under the Reagan administration, national security has become a watchword in virtually all technology areas, and space is no exception.

There are many different types of cooperative programs, primarily sponsored by NASA, ranging from the exchange of scientists to joint development of spacecraft. One of the largest categories of cooperation has to do with the reception of data gathered by U.S. satellites, especially meteorological and remote-sensing satellites. The NASA-developed automatic picture transmission (APT) station for receiving data from polar-orbiting weather satellites is in common use throughout the world, so much so that agreements are no longer signed for their use. The equipment is available through several international outlets.

The direct reception of land remote-sensing data from Landsat satellites, however, does require signed agreements. At the end of 1982, when this article was drafted, eleven foreign Landsat ground stations were in operation at the following locations: Argentina, Australia, Brazil, Canada (two stations), India, Italy (owned by the European Space Agency, ESA), Japan, South Africa, Sweden (owned by ESA), and Thailand. In addition, Indonesia and China have signed agreements to build ground stations, and several other countries have indicated interest. (Three agreements, with Chile, Iran, and Zaire, have lapsed.) Each country pays an annual access fee ($600,000 beginning in October 1982) and agrees to provide the United States with any data it needs. Originally, NASA was responsible for these agreements, but with the transfer of the operational Landsat program to the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), the latter agency has taken over these activities.

NASA sponsored a program for assisting countries in interpreting remote-sensing data from Landsat 1 and 2

and the Skylab EREP (Earth Resources Experiment Package) program. Approximately fifty countries participated, with NASA selecting individual experiments according to scientific merit. No exchange of funds was involved. Although the NASA program has been terminated, the Agency for International Development (AID) sponsors seminars throughout the world to demonstrate the value of remote-sensing data and has established three regional remote-sensing centers (in Thailand, Kenya, and Upper Volta).

A third category of cooperation concerns the launch of satellites. There are two types of agreements, cooperative and reimbursable. In a cooperative launch, there is no exchange of money; instead, data and services are exchanged. For example, the United States might launch a satellite in which the payload has been developed jointly, or a foreign country may provide the entire spacecraft; in return, U.S. scientists are given access to the data. In a reimbursable launch, a country pays to have the United States launch a satellite (usually for communications). Through the end of 1982, there had been twenty-nine cooperative launches and thirty-eight reimbursable launches (not including thirty-three for the International Telecommunications Satellite Organization, INTELSAT). Italy has also launched several U.S. satellites, using U.S. launch vehicles, from its San Marco platform off the coast of Kenya.

The programs designated "cooperative," rather than those that are "reimbursable," probably represent what most commonly comes to mind when discussing cooperative space activities in which both sides contribute to the development of a space program and the analysis of the data. Throughout the history of the space program, most such missions have involved U.S. spacecraft on which the United States has offered foreign scientists the opportunity to fly experiments; in a few cases, though, the other country has provided the entire spacecraft for launch by the United States (e.g., the Helios spacecraft built by Germany for solar studies). Also, the Soviet Union has launched a few spacecraft that carried U.S. experiments. With the attainment of independent launch capabilities by other countries (notably the European Space Agency), the situation is now reversing to some extent, and opportunities exist for U.S. scientists to fly experiments on foreign satellites at a time when the U.S. space-science program suffers from budget constraints. U.S. international space activities are extensive and cannot be treated comprehensively here. A few examples of cooperative endeavors, both successful and not so successful, are provided below.

Cooperation with the Soviets

The most visible example of international cooperation is the 1975 Apollo-Soyuz Test Project (ASTP) with the Soviet Union. The United States launched a three-man crew in an Apollo spacecraft to dock with a two-man crew in a Soviet Soyuz. The five men exchanged pleasantries and gifts and conducted several scientific experiments in the two days that the ships were docked together. After undocking, the two ships conducted docking and eclipse experiments for two days. The Soyuz then returned to earth while the Apollo remained in orbit for three more days to conduct additional scientific experiments.

The ASTP mission was notable primarily because it involved cooperation between two traditional space competitors. There had been little cooperation between the United States and the Soviet Union through the 1960s, although agreements had been signed in 1962 and 1965. In 1969, NASA initiated talks for new cooperation which led to a 1970 agreement to study the possibility of a joint manned mission. In 1972, an accord was signed by President Nixon and Soviet Chairman of the Council of Ministers Kosygin which led to ASTP.

The ASTP mission was criticized as an expensive method of demonstrating the warming of relations between the two countries. Some feared, also, that the United States would be giving away advanced space technology to the Soviets. Seven years later, however, it is difficult to point to a single example of new space technology being used by the Soviets that might have come from their experience with ASTP (except for the remodeling of the Soviet mission-control center to resemble the one at NASA's Johnson Space Center). While U.S. engineers did not take home invaluable technical expertise either, at least some new information was gained about the secretive Soviet space program. U.S. astronauts and support personnel were allowed to visit the Soviet launch facility at Tyuratam, and were able to study the Soyuz spacecraft (later noting that it was closer to America's 1965-era Gemini spacecraft than to an Apollo). The West also obtained details of a 1971 Soviet space mission in which the three-man crew died during reentry—information that might not have become available without ASTP.

Another cooperative agreement, signed in 1977, included the suggestion that a mission involving the U.S. space shuttle and the Soviet Salyut space station be pursued. In addition, the Soviets offered to fly U.S. experiments on several of their biological satellites. The first such mission had been successfully accomplished in 1975, and three more were envisioned in the 1977 agreement (two were flown in 1977 and 1979, and the third was scheduled for late 1983). American scientists have reported excellent cooperation from their Soviet colleagues not only in these biological satellite programs, but also in the exchange of data from planetary flights (particularly Venus) as well as biomedical data from the Soviets' long-duration manned spaceflights (the longest such flight to date has been 211 days, compared with 84 days for the United States).

U.S.-Soviet cooperation cooled following the Soviet invasion of Afghanistan in 1979. The 1977 agreement expired in May 1982, and President Reagan decided not

to renew it because of Soviet involvement in Poland. Thus, as of the end of 1982, there was no official cooperative agreement between the two countries. Two programs begun under the 1977 agreement were allowed to continue, however: the biological satellite mission mentioned above and an international program for satellite-assisted search and rescue, called COSPAS/SARSAT. A Soviet satellite carrying the first of a new generation of transponders, capable of pinpointing aircraft and other vehicles in distress, was launched in the summer of 1982 and within a short time had been responsible for the safe return of a three-man airplane expedition that had crash-landed in Canada. A U.S. transponder was launched on the NOAA-8 weather satellite in 1983, and a second Soviet satellite was also launched in 1983.

The European Space Agency was established in 1975 as a merger of two separate organizations for developing launch vehicles (ELDO, the European Launch Development Organization) and satellites (ESRO, the European Scientific Research Organization). The United States had a history of cooperation with ESRO that continued with the creation of the new agency. ESA now has eleven member countries (Belgium, Denmark, France, Germany, Italy, Ireland, the Netherlands, Spain, Sweden, Switzerland, and the United Kingdom), two associate members (Austria and Norway), and a technical agreement of cooperation with Canada.

Already mutterings can be heard that NASA is attempting to stimulate international support in order to make it more difficult for the Reagan administration, and eventually the Congress, to reject the space station idea.

Extensive cooperation has taken place between the United States and ESA, and the largest of these programs was ESA's development of a module called Spacelab for use with the U.S. space shuttle. Under the terms of the original agreement, signed in 1973 with ESRO, the Europeans designed, developed, manufactured, and delivered one Spacelab module free to NASA, which had the option to buy additional units. The pressurized unit fits inside the cargo bay of the space shuttle, providing a shirt-sleeve environment for scientists to conduct experiments. The agreement benefited both sides, providing the United States with a needed component of its space transportation system while European industry gained an opportunity to expand into new technological areas.

The first Spacelab was delivered to NASA in the spring of 1982 and was scheduled to fly into space in November 1983. Although difficulties were encountered, primarily because of changing NASA requirements which in turn led to redesign of certain Spacelab components, the overall program has been quite successful. The major ESA disappointment is that NASA has agreed to purchase only one additional Spacelab unit, but the Europeans are promoting the concept of building permanent space stations by docking several Spacelab modules together. At the very least, the knowledge gained by ESA and by European companies will put them in a favorable position to participate in a manned space station program, should the United States choose to pursue one, and it could enable them to build space stations of their own.

Another type of cooperation is exemplified by a 1975 program with India called SITE (Satellite Instructional Television Experiment). In this instance, the United States lent its ATS-6 satellite (Applications Technology Satellite 6) to India for one year in order to perform experimental broadcasts of television programs to remote villages. Programming was developed by the government of India to provide instruction in health, family planning, education, and agriculture. The programs were broadcast in eight languages (Hindi, Kashmiri, Bengali, Oriya, Marathi, Gujarati, Tamil, and English) directly to small receivers in 2,200 villages. Another 2,000-3,000 villages were able to receive the broadcasts through secondary-transmission methods.

The experiment was considered a tremendous success, and led to the development of a satellite by India for continuing these activities. The satellite, Insat 1, was launched by the United States on a reimbursable basis in April 1982, but a problem with the fuel supply led to the cessation of operations in September of that year. A back-up satellite, Insat B, was launched in 1983 and became operational in October, continuing television broadcasts to remote villages and providing point-to-point communications and meteorological information.

Where the Problems Are

The vast majority of cooperative programs have been extremely successful, but I would be remiss not to mention a few of the difficulties that have arisen in recent years. By and large, these problems have not been caused by the U.S. agencies involved in program implementation, but rather by budgetary constraints within NASA, new concerns about technology giveaway, and U.S. policy regarding launch assurances for foreign countries.

In 1979, NASA and ESA signed a memorandum of understanding to conduct a program called the International Solar Polar Mission (ISPM, formerly called the

Out-of-the-Ecliptic Mission) for launch in 1983. The two agencies were each to provide one spacecraft for studying the polar regions of the Sun. Such a study would require the spacecraft to fly out of the plane of the ecliptic (in which the planets orbit the Sun), requiring a great amount of energy. Thus, the mission envisioned sending the two probes toward Jupiter, where the giant planet's gravity field would be used to swing the spacecraft up and out of the ecliptic and back toward the Sun. With two spacecraft, simultaneous readings could be made of both poles. Besides providing one of the spacecraft, NASA agreed to launch both spacecraft, provide tracking and data acquisition services, and give ESA a radioisotope thermal generator (RTG) to power its spacecraft.

The program encountered funding problems from the very beginning. NASA requested ISPM as a new start in its FY 1980 budget, and although the program was approved by Congress, the chairman of the House Appropriations subcommittee having jurisdiction over NASA programs sent a letter to the NASA administrator in December 1979, directing NASA to postpone the mission for two years. One problem cited by the committee was the delay encountered in the development of the space shuttle which would be used as a launch platform for the spacecraft. Moreover, the committee was concerned that the upper stage that was planned to send the two spacecraft on their journey (the inertial upper stage, IUS) would not be adequate for the job, and NASA should develop a high-energy upper stage (Centaur) instead. Although NASA was not persuaded by these arguments, the agency subsequently postponed the launch of ISPM to 1985 as a budget move.

In the spring of 1980, the House Appropriations Committee recommended in the FY 1980 supplemental appropriations bill that ISPM be terminated and that some of the money appropriated for FY 1980 be rescinded. In response, several member countries of ESA formally protested to the State Department, which then came to the aid of the program in Congress. The program was saved, but only temporarily.

The final blow to ISPM came in 1981 when President Reagan submitted his first budget request to Congress, which recommended termination of the U.S. spacecraft for ISPM, although support for the ESA spacecraft (launch, tracking, and data acquisition as well as the RTG) was maintained. This action was taken unilaterally, without prior consultation with ESA. At the same time, NASA decided that it would develop the Centaur upper stage instead of the IUS after all, thus necessitating changes in the ESA spacecraft.

Once again, protests were lodged with the State Department and NASA, but this time to no avail. ESA Director General Erik Quistgaard, in testimony before the House Science and Technology Committee, reminded the members that ESA had chosen ISPM over several other potential scientific programs because of the value it attached to cooperation with NASA, and that ESA had already spent $100 million on the program. Congress provided NASA with $3 million to keep the program alive, but the Office of Management and Budget (OMB) informed NASA that it would not support funding for the program in future years, although it would allow NASA to reprogram funds from other space-science projects.

One can expect that the European Space Agency will want certain guarantees from NASA in order to prevent unilateral cancellation of cooperative programs. ESA will, at the least, want to limit its financial liability in the event of a cancellation.

After considering several options, including the possibility of purchasing a spacecraft from ESA, NASA finally decided that it could not afford ISPM without OMB support.

ESA later decided that it would continue with its spacecraft plans, but sought assurances from the United States that future budgetary actions would not terminate NASA's promise to launch the probe, provide tracking and data acquisition services, and provide the RTG. Although ESA sought an earlier launch opportunity as recompense for U.S. cancellation of its spacecraft, the launch date for the mission has slipped an additional year; the Centaur upper stage will not be ready until 1986.

Assessment of the long-term impact of the ISPM incident is difficult because no further ESA-NASA agreements have been signed since then. ESA has continued to express interest in cooperating with NASA on space-science programs (and possibly on a space station), but one can expect that the agency will want certain guarantees written into future memorandums of understanding in order to prevent unilateral cancellation of such programs or at least to limit its financial liability in the event of a cancellation. NASA faces the problem, however, of having to place contingency clauses in such agreements, to the effect that continuation of a given program is subject to appropriations which make that program vulnerable to annual reviews by both the administration and the Congress.

Another type of problem encountered in international

programs because of budget constraints has to do with continuity of effort. Only two examples will be cited here: Landsat activities and communications support to some Pacific islands.

The Landsat program provides multispectral data that can be used to survey natural resources, to study the effects of pollution, to assist in land-use planning, and to monitor crops and provide crop-yield estimates. The United States has launched four Landsat spacecraft and one more is planned, but beyond that the future of the program is uncertain. The government wants the program to be taken over by the private sector, but since there is not yet a large enough market for land remote-sensing data to guarantee a profit, there has been a dearth of proposals by the private sector to take over the program without government subsidies. Thus, users in foreign countries (as well as in the United States) are concerned that they might invest large amounts of money, either in purchasing Landsat receiving stations or in training personnel to use the data, only to have the United States terminate the spacecraft segment. Another aspect of the Landsat problem is that programs providing for direct U.S. support (formerly through NASA and currently through AID) for the training of foreign scientists in the interpretation and use of Landsat data are in danger of being terminated because of budgetary constraints.

The 1975 Apollo-Soyuz project, the most visible example of international cooperation, was notable primarily because it involved cooperation between two traditional space competitors.

The lack of continuity in U.S. programs is also evident in the communications area. The PEACESAT program, for instance, has provided communications services to certain Pacific island nations since 1971, using the ATS-1 satellite. The satellite is now at the end of its lifetime, and there is no satellite with which to carry on this service. Suggestions have been made for using one of the older INTELSAT satellites, but that would require installation of different ground stations. Another option is to use transponders on one of NASA's tracking and data-relay satellites, but that would require repointing one of the satellite's antennas (and NASA has indicated an unwillingness to do so). Thus, this communication service may end in the near future.

The debate over technology transfer has many components. Technology that the United States provides to other countries might become an instrument of competition with U.S. companies. Technology transferred to a country with which the United States has strained relations might be diverted to military purposes. And technology initially transferred to a friendly country might end up in the hands of a nation with which the United States is not so friendly, either through the capture of U.S. equipment during the overthrow of a friendly government or because a friendly country serves as an intermediary between the United States and an unfriendly country. An example of the latter is offered here.

In 1978, the Arab League, comprising twenty-one Arab countries and the Palestine Liberation Organization, decided to purchase a regional communication satellite system. This satellite system, ARABSAT, will consist of three geostationary communication satellites. The ARABSAT contract was won by Aerospatiale, a French company, teamed with Ford Aerospace in the United States.

In order to provide Aerospatiale with satellite technology, Ford Aerospace required a technology export license, which must be approved by the Senate. In the fall of 1981, the State Department forwarded the request for such a license to the Senate. Unfortunately, this request came shortly after a stormy Senate debate over the provision of AWACS technology to Saudi Arabia, resulting in raised concerns about technology transfers to the Middle East.

When it was learned that the satellite system would be used by the Arab League, which includes countries currently out of favor with the United States, several members of the Senate felt that the export license should be denied. The State Department withdrew the request, and several weeks of briefings by Ford Aerospace (which would have lost $20 million and 5,000 jobs), the Department of Defense, and the State Department followed. Finally, the senators relented, realizing that the technology was being transferred to France, not to Arab countries, and that the satellites themselves would be in geosynchronous orbit, well out of the reach of any country. The request for an export license was reintroduced and not opposed. A major problem resulting from this controversy is whether U.S. companies will be considered reliable international partners in such endeavors in the future or whether U.S. government approval will be required before a foreign company will sign such an agreement.

Yet another type of problem encountered in the international space business relates to launch assurances. In this case, it is a matter of what types of satellites the United States will agree to launch for another country, even if that country is paying for the launch. The United States, for example, will not launch satellites for other countries when its national security might be adversely affected. The assumption can be made that this proscrip-

tion would include military reconnaissance satellites, which may be desired by other countries. Nor will the United States launch satellites that would interfere with its responsibilities under other international agreements; a case in point is the INTELSAT agreement.

The United States sponsored the formation of INTELSAT in the 1960s (and, in fact, INTELSAT is a good example of a highly successful U.S. international space initiative). One section of the INTELSAT charter states that signatories must agree not to launch satellite systems which might cause economic harm to the INTELSAT system—that is, INTELSAT and INTELSAT alone will provide international satellite communication services. In 1967, however, Germany and France decided to develop a satellite system called Symphonie, for launch in 1974, that would be capable of providing communications between Europe, Africa, the Middle East, and North and South America. Asked to launch the satellites, the United States responded that such a system would be competitive with INTELSAT and that the United States therefore could not provide launch services without violating the INTELSAT agreement.

Eventually, the two Symphonie satellites were launched by the United States after Germany and France formally stated that the system was experimental, not operational. Although plans were already under way at that time for constructing a European launch vehicle capable of placing communications satellites in orbit, the Symphonie incident is often credited with having provided the final impetus to the Europeans to construct their own launch vehicle (Ariane) so they would not have to depend on the United States.

It should be noted that a number of regional communication satellite systems (such as ARABSAT) are now planned. To date, these regional systems have been approved by INTELSAT on a case-by-case basis to ensure that they provide regional rather than international service. A 1982 decision by INTELSAT to approve a European regional satellite system being built by the EUTELSAT consortium for only a five-year period, after which another review will take place, has raised the ire of several European countries. With the growing interest by individual countries and groups of nations to have their own satellite systems, INTELSAT will almost certainly have to review its position on competitive systems if it is to survive through the 1980s.

The United States may also have to review its policy regarding what types of satellites will be launched. While the United States cannot be expected to launch satellites that might negatively affect its national security, the question of which other categories of satellites might also be refused is not so clear. This issue will become increasingly important as nongovernmental entities such as Space Services Inc. begin providing launch services.

With respect to international space policy, the future appears quite bleak. Some issues—relating to direct-broadcast satellites, remote sensing, and access to geostationary orbit—have been debated for more than a decade.

The Politics of Cooperation

In addition to the practical, scientific, economic, and national security aspects of international space cooperation, there are definite political components. These can take several forms. For example, NASA has been accused (with increasing frequency) of using international cooperation to win approval for its programs, both within the administration and the Congress. Whether or not the allegation is true, during the late 1970s, when NASA's space-science budget began to dwindle, an oft-repeated NASA theme in testimony before congressional committees was that other countries were participating in a particular program and that its cancellation would therefore create international discord. The ISPM is a case in point.

This approach worked quite well until the Reagan administration, when such arguments became ineffective within the executive branch (it was the administration, not Congress, that canceled ISPM). Nevertheless, NASA has been trying to persuade the administration to support construction of a space station as the next major NASA program. Such approval has not been forthcoming, and NASA is reportedly embarrassed by the fact that others (notably ESA and Japan) are publicly offering to cooperate with NASA in such an endeavor. Already mutterings can be heard that NASA is attempting to stimulate international support in order to make it more difficult for the administration, and eventually Congress, to reject the space station idea.

Another way in which politics influence cooperation is exemplified by the current state of U.S.-Soviet cooperation. As noted, there are no longer any formal cooperative agreements between the United States and the USSR. The only existing U.S.-Soviet space programs are continuations of two that had begun earlier: the search-and-rescue satellite program and the biological satellite program. (This latter program is also interesting from a political point of view because of the pressure brought to bear on Congress by antivivisectionists who,

concerned about the treatment of the two rhesus monkeys that will be flown, want the flight canceled. Apparently they do not realize that the monkeys are being provided by the Soviet Union, so no U.S. action can prevent the flight.)

International politics can also play a role in space activities, although less in specific programs (such as scientific probes) than in overall policy. The United Nations

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If it is to survive through the 1980s, INTELSAT will almost certainly have to review its position on competitive satellite systems.

Committee on the Peaceful Uses of Outer Space (COPUOS) serves as a forum for the discussion of international space issues. Through its legal and scientific and technical subcommittees, recommendations are made for treaties and other agreements on international space issues. Five treaties have been developed by COPUOS, of which the first four are in force: the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (the Outer Space Treaty); the 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space; the 1973 Convention on International Liability for Damage Caused by Space Objects; the 1976 Convention on Registration of Objects Launched into Outer Space; and the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies. The United States is a signatory to all but the last of these.

Other issues debated within COPUOS include principles governing direct-broadcast satellites and remote-sensing data, the use of nuclear power sources on spacecraft, the definition and delimitation of outer space, use of geostationary orbit, and technology transfer. Besides the COPUOS activities, the Committee on Disarmament, which is closely associated with the United Nations, is considering issues involving the "militarization" of space and whether to establish an international agency to allow the UN to monitor treaty compliance in times of crisis by means of reconnaissance satellite data.

All of these issues were discussed in August 1982 at the Second UN Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE '82). The United States was one of ninety-four countries represented at the conference, which was sponsored by COPUOS and was to serve as a forum for demonstrating the advantages of space activities to developing countries (particularly in such areas as remote sensing and communications).

The two-week conference, rather than focusing on technical subjects, became embroiled in a controversy over whether the conference report should include language expressing the concern of the international community over the perceived "militarization" of space. The United States contended that the topic of militarization had been referred to the Committee on Disarmament and was therefore inappropriate to discuss at UNISPACE '82, which was sponsored by COPUOS. All the other countries thought it was quite appropriate since the military uses of space can affect peaceful ones. COPUOS, moreover, has a direct interest in the topic since it originated the text of the 1967 Outer Space Treaty, which addresses the military uses of space in Article 4 (banning the use of nuclear weapons or other weapons of mass destruction in space). After two stormy weeks of debate, three paragraphs reflecting concern about the arms race in outer space were finally adopted. This language was a partial victory for the United States, since it wanted to differentiate between military uses of space (which include activities such as reconnaissance, communications, and navigation) and the arms race in outer space, which Washington perceived to be the cause of the international concern about military activities in space.

Other controversial topics discussed at UNISPACE '82 mirrored debate within COPUOS over the past decade. The dispute over whether a country should have the right of prior consent with respect to the television signals transmitted into its borders by direct-broadcast satellites (DBS) was not resolved at UNISPACE '82. During the UN General Assembly meeting in the fall of 1982, however, a resolution was passed which adopted draft principles that had been developed in COPUOS but had been opposed by many Western nations (including the United States). The resolution has the status of a nonbinding recommendation; its impact is therefore unclear.

Nor was the question of whether a country should have prior consent over the distribution of satellite remote-sensing data on its natural resources resolved at UNISPACE '82, and this issue remains under discussion within COPUOS. As in the case of DBS, the United States opposes restrictions on the distribution of data, citing its free-flow-of-information doctrine.

The issue of guaranteed access to geostationary orbit (GEO) was also highly controversial at UNISPACE '82. A satellite placed in GEO, located 35,800 kilometers above the equator, maintains a fixed position relative to any point on earth and is therefore quite useful for communications satellites. Developing countries are concerned that developed nations will use all the "good" orbital slots and frequencies in GEO, so that none will be available when they want to launch such systems. Con-

sequently, the developing countries want "a priori" plans to be established whereby every country would be guaranteed a place in GEO, whether or not the nation has a plan to utilize it. Developed countries generally oppose such planning because it would deny them access to orbital slots and frequencies which might never be used by the countries to which they are assigned.

This issue is primarily debated under the auspices of the International Telecommunication Union (ITU), a specialized agency of the United Nations. An a priori scheme was negotiated for two-thirds of the world in 1977, for direct-broadcast satellites operating at the 12-gigahertz frequency range, and in 1983 a separate ITU meeting decided the planning scheme for the remainder of the world (North and South America).

The future of international cooperative space programs looks bright if for no other reason than the tight budgetary conditions throughout the world. Nations are becoming increasingly intrigued by the possibilities for commercial applications and scientific endeavors on the space frontier. With cooperative ventures, more can be accomplished.

Despite the ISPM incident, ESA is still interested in cooperating with the United States, and notwithstanding current tensions between the United States and the USSR, one can hope that relations will improve and that new cooperative endeavors can be started in five to ten years. Japan has shown considerable willingness to cooperate with the United States and has plans to select an astronaut to fly on the space shuttle, as do Australia, Britain, Canada, and France. Other countries may also have a chance to fly their own astronauts on the shuttle—President Reagan made such an offer to Brazil at the end of 1982. The Soviets are also flying cosmonauts from foreign countries, and ten have flown already (from Bulgaria, Cuba, Czechoslovakia, East Germany, France, Hungary, Mongolia, Poland, Rumania, and Vietnam). Space is becoming truly internationalized.

The biggest problem confronting the United States in future international space ventures is the budgeting process in which OMB and Congress make yearly decisions on whether or not to continue a program, rather than approving a project for its lifetime. It is not likely that the budgeting process will change, and this raises questions about how the United States can prove that it is a reliable international partner.

With respect to international space policy, the future apears quite bleak. Issues such as prior consent for direct-broadcast satellites, remote sensing, and access to GEO have been debated for more than a decade, and there is little hope that an amicable resolution will ever be reached. Thus, the viability of the international structure for resolving these disputes is being questioned; although, in all fairness, the utility of the UN system as a whole—not just those components that deal with space—has been a matter of great concern to the Reagan administration. Hence, the United States threatened to pull out of the ITU and possibly the UN itself because of a highly politicized ITU meeting in 1982. In that case, the meeting of the ITU, which is theoretically a technical organization for allocating the radio frequency spectrum and orbital slots, degenerated into a political free-for-all when some countries attempted to expel Israel because of its activities in Lebanon. The issue had nothing to do with the agenda of the meeting, but brought to a halt all work at the conference for most of its six weeks. Future U.S. participation in the ITU remains in doubt.

Bilateral and multilateral space cooperation should thrive, but it should be mentioned that competition will also increase. The ESA Ariane launch vehicle, despite two failures out of its first six launches, poses a real competitive threat to the U.S. space shuttle. France and Japan have developed advanced technology for communications satellites, and France is also planning to launch a remote-sensing satellite that will compete with the U.S. Landsat. While cooperation has been a major component of the U.S. space program for the past twenty-five years and will remain so for the indefinite future, competition is likely to play an increasingly important role in setting the stage for the long-term exploration and exploitation of space.□

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Marcia S. Smith is a specialist in aerospace and telecommunications systems with the Science Policy Research Division of the Congressional Research Service, Library of Congress. She is the author of more than sixty articles and reports on such topics as space programs, communications, and nuclear energy.

Gold Rush in the Clarke Orbit

Joseph N. Pelton

It is remarkable how consistently innovations and "miracle breakthroughs" give rise to new and unsuspected social, economic, and political problems. The use of fire is the ancestor of today's energy problem. Urban renewal problems would never have happened without the invention of farming, which made possible permanent human settlements. At the turn of the twentieth century, the members of the London City Council were agonizing over a major concern that they feared would bankrupt the city treasury—namely, how (short of financial disaster) hundreds of tons of horse manure might be removed from the streets of their fair city. The introduction of the horseless carriage was, in its day, greeted as an ecological and financial godsend for the keepers of the city's purse. The automobile, like hundreds of major technological developments before and after, has stimulated progress, while at the same time giving rise to new and unexpected social issues and problems.

Clearly it is difficult to project the future and visualize the development of new industries; once established, however, new services and products soon produce dependencies. Our modern, sprawling cities are totally dependent on modern transportation and communications systems. Although automobiles, chemicals, and computers now give rise to "problems," we cannot just stop using them—at least not without causing serious disruptions to society, perhaps even risking severe damage to modern civilization. Abandonment of modern technologies is, in a practical sense, nearly impossible. This "impossibility factor" certainly applies to our global talking machines—the communications satellites. Pull the plug on the emerging network of domestic, regional, and international satellite communications systems that exist around the world and one is likely to pull the plug on the global economy.

Given the size of the satellite communications industry, it is remarkable that it really all began less than twenty years ago. The entire industry, including satellites, earth stations, launch services, insurance, tracking, telemetry, and command operations, plus the value of the services they carry, will probably near $100 billion by the late 1980s., with perhaps 90 percent of this involving services and 10 percent representing equipment and facilities.

In April 1965, the world's first transoceanic satellite system, known as INTELSAT, was created. At the end of its first year of operation, this satellite system had in service only seventy-five voice circuits. In those days, all telephone service on the satellite had to be surrendered to allow a medium-quality black-and-white television channel to be transmitted across the Atlantic Ocean.

It was from these modest beginnings, however, that the phrase "live via satellite" became a part of our contemporary culture. By 1969, three INTELSAT satellites (positioned over the Atlantic, the Pacific, and the Indian Ocean regions) allowed some 500 million people, the world over, to see the first moon landing live. From the embryonic satellite system inaugurated by Early Bird in 1965, a vast global network, including scores of domestic and special-purpose communications satellite systems, has now emerged. These systems are almost unrecognizable, in terms of scope and complexity, when compared to the simple devices of the early days.

The INTELSAT system now carries virtually all live international transoceanic television broadcasts, as well as 60,000 full-time telephone channels, on more than 1,100 preassigned pathways to interconnect more than 160 countries, territories, and independent possessions around the globe. Furthermore, domestic communications are provided by INTELSAT, under long-term space-segment leases, to more than 20 countries. This service is expected to grow to involve more than 40 countries by the mid-1980s. Separate domestic and regional satellite systems now in operation or planned presently number more than 50. An astonishing array of some 120 communications satellite systems will inhabit geosynchronous orbital space by the mid to late 1980s. Yet, at the consumer level, this proliferation of communications satellites and the growing dependence on satellite communications is invisible and would be noticeable only if these vital services were to disappear.

What's the Problem?

The communications satellites of the 1980s, unlike their forebears of the late 1950s and early 1960s, are complex devices that are typically launched into geosynchronous orbit, sometimes called the Clarke Orbit. There they can continuously provide a wide range of communications services to users who access the satellites through ground antennas. These multibillion-dollar

satellite services (which include telephone, telex, facsimile, electronic mail, television, video conferencing, computer networking, and data communications) are now vital means of national and global communications. These new satellite-delivered services are more cost-effective and versatile than past ways of communicating.

What, you may ask, could possibly be wrong with all this? Unfortunately, the answer is, plenty. First, there is the issue of transborder information flow. Communications satellites are able to relay information across international boundaries, thus giving rise to concerns about privacy of information, the intrusion of foreign interests into domestic economies, and unwanted political, cultural, commercial, or religious messages being beamed into a country without the cooperation or permission of the local government. Particularly within the United Nations and UNESCO, these issues have been given increasing prominence; serious rifts between North and South as well as between East and West have occurred. Many countries are moving to create national laws to protect their "domestic industries" in the transborder data-flow struggle. (It is ironic that the International Telegraph Union, now the International Telecommunication Union [ITU], was created in 1865 to cope with this same issue of transborder data flow, though in the context of the telegraph.)

A second major concern relates to the issue of international equity and equality of access to communications satellite services. Since deployment of communications satellites requires a sophisticated technological base and considerable financial resources, many Third World countries have become very concerned about the increasing number of geosynchronous communications satellites being deployed by the developed countries. These concerns include the fear that by the time Third World countries are ready to deploy or utilize their own communications satellite system, there may be insufficient locations remaining in the Clarke Orbit. These issues came to a head at the ITU's World Administrative Radio Conference (WARC), held in Geneva during 1979. This concern was most pointedly expressed in terms of opposition to the status quo principle of first come, first serve.

A third series of problems relates to competition. There is today competition between technological media such as satellites and submarine cables and, by direct extrapolation, between aerospace and cable manufacturers. Likewise, there is an emerging competition between domestic, regional, and international satellite systems. This process of competition has been further promoted by the U.S. government's attempt to "deregulate," "commercialize," and "diversify" the market in the field of telecommunications. Finally, there is an emerging rivalry among the different types of satellite communications service requirements, such as fixed satellite services versus broadcast satellite services, mobile satellite communications services, or radio-location (radar) services.

Some have suggested that communications satellites should ultimately be reserved for those applications which best make use of the unique characteristics of satellites, such as multipoint-to-multipoint broadcasting or mobile services. Others strenuously argue that satellite communications facilities should continue to provide all forms of services, with demand and marketplace considerations being the prime consideration.

The resolution of these questions will largely depend on which radio frequencies are made available for satellite communications within the framework of the ITU international negotiations and decisionmaking process. Over the next five years, technical debates will focus on which higher radio frequencies are to be utilized for satellite communications, and when; whether certain applications or geographic areas should be given prime access to the lower (more desirable) radio frequencies; and whether accommodation and agreement can be reached between developed and developing countries to meet all technical, operational, and service needs.

The issue of frequency allocation and use within the ITU forum involves not only communications satellites but terrestrial communication applications, as well. There is frequently a dispute over whether terrestrially based use of the lower radio frequencies should be primarily for telecommunications services (a view primarily expressed by developing countries) or primarily for broadcasting and mobile communications services (primarily espoused by developed countries). Other technology-related issues have to do with the continued use of "conventional" dedicated communications satellites (which have now been in service for the past fifteen to twenty years) versus the concept of large and increasingly complex multipurpose space platforms. Some feel that consolidation of a large number of service requirements and a range of different radio frequencies into a single, very large spacecraft makes much more efficient use of the geosynchronous orbit and is preferable to continuing the trend toward proliferation of conventional satellites. The above issues, which of course have many key technical aspects, involve conflicting industrial and economic interests, particularly with respect to the U.S., Japanese, and European aerospace, communications, electronics, and cable industries.

Although this has hardly been a comprehensive list of the issues that have arisen from the successful development of the communications satellite over the past fifteen or twenty years, it does suggest the range of economic, political, and social issues confronting the field today. Since I cannot here explore all these issues in depth, I shall focus attention on what is probably the primary political and technological issue now confronting the ITU, INTELSAT, and the many national communications satellite industries (particularly in light of the WARC meetings scheduled for 1985 and 1987). How can equitable and beneficial access to the geosynchronous orbital arc be assured to all countries, whether they are developing, industrializing, or highly developed information societies. In particular, will such access be based on opportunity, resources, or need?

Into the Diplomatic Maze

To understand the dimensions of this problem and the international procedures to deal with the issue of orbital assignment and geosynchronous arc, one must know more about the major institutions involved. These include the following:

- *The International Telecommunication Union*, responsible for international regulations concerning the use of all the world's electromagnetic spectrum for communications and scientific research.
- *The International Frequency Registration Board* (IFRB), the unit within the complex ITU structure which maintains the master register of frequencies and records the successful conclusion of intersystem coordination agreements for all satellite systems.
- *The International Committees on Telegraph and Telephone and the International Committee on Radio* (in their French abbreviations, the CCITT and the CCIR, respectively). These international committees develop internationally agreed recommendations for communications standards in the fields of electronic telecommunications, radio, telegraphy, and television.
- *The International Telecommunications Satellite Organization* (INTELSAT), which operates under two international agreements and now provides two-thirds of the world's overseas telecommunications services for some 160 countries, territories, and independent possessions, as well as domestic communications services for more than 20 countries.
- *The International Maritime Satellite Organization* (INMARSAT), an entity created under two international agreements for the purpose of providing international maritime satellite services.
- *UNESCO*, the UN specialized agency responsible for communication at the level of mass media, journalism, and culture. Recently, through a new subsidiary entity known as the International Programme for Development of Communications, UNESCO has become increasingly involved in transborder data-flow and telecommunications development issues.

Besides the above, there is a host of other orgnizational entities engaged in the provision of satellite communications service facilities. Today, literally thousands of people are involved in the very complicated field of international diplomacy vis-à-vis satellite communications.

Every twenty years, in theory, the International Telecommunication Union holds a World Administrative Radio Conference, among its entire membership, to review and revise global radio regulations, including the table of radio-frequency allocations. The ITU's radio regulations are a vast complex of recommendations, tables, and charts, sprinkled liberally with highly technical explanatory footnotes. This forbidding document, together with masses of CCIR and CCITT documents, forms the foundation of the worldwide regulatory system for satellite communications as well as for all other modern forms of communications. These formidable radio regulations are of the utmost importance not only to the multibillion-dollar satellite communications industry but, indirectly, to an increasing portion of the world economy as a whole.

The field of modern telecommunications is evolving very rapidly, not only technologically but also in its political and social dimensions. Consequently, the practice has evolved of holding a large number of international conferences, at much more frequent intervals than the traditional "every 20 years," in order to deal with this complexity. Thus, recent years have seen specialized administrative conferences on satellite broadcasting, medium-frequency broadcasting, maritime communications, and so on. These might be thought of as "kissing cousins" to a full-scale WARC. In addition to dividing the WARC process into sectors related either to services, technologies, or radio-frequency ranges (or indeed a combination of these), the ITU has found it useful to divide the world up into three regions: *Region 1*, Europe, Africa, and the Middle East; *Region 2*, the Americas; and *Region 3*, Asia and Australasia. Regional conferences are also held to deal with subjects relating to one or another specific issue. These sessions, then, called Regional Administrative Radio Conferences (RARCs), are like third cousins once removed from the twenty-year-old WARC. In 1983, for instance, there will be an RARC for Region 2, devoted to the allocation of radio frequencies for broadcasting satellite services.

Thus, one must contend with a labyrinthine maze of activities within the ITU structure. These include the complex intricacies of the CCIR and CCITT, with nearly fifty working groups; the WARC's own special preparatory meetings; the Specialized Administrative Radio Conferences plus the RARCs; the plenipotentiary meetings of the ITU; and the meetings of the ITU's Administrative Council. Seldom does a week go by that there is not some ITU meeting held somewhere in the world. On the one hand, this elaborate process is a remarkable example of international cooperation at the scientific and technological level. It has been said that one form of tyranny is to impute simplicity where it does not exist. Complexity is a necessary response to the "high-tech," rapidly developing field of telecommunications. On the other hand, the necessity of having a high level of expertise to participate in ITU meetings is in itself a major concern of the developing countries, which lack both the expertise and the financial wherewithal to participate at the same level as such advanced countries as the United States, the Federal Republic of Germany, France, and Japan.

The ITU, which is the world's oldest universal-membership intergovernmental international organization, has been swept up in the winds of change during the past decade and a half. Initially, the ITU was designed to coordinate European telegraphy. Reconstituted as the International Telecommunication Union in 1932, the ITU was given a broader mandate: to cover all elements of telecommunications and particularly to establish regulations for the practical and scientific use of the

electromagnetic spectrum. As late as 1945, the ITU had a total membership of just over 70 countries. As such, it was largely dominated by OECD (Organization for Economic Cooperation and Development) countries. However, by 1982, the rapid emergence of new countries had pushed the membership of the ITU to more than 150. The largest specialized agency in the UN system, the ITU has more members than the United Nations itself. Since the ITU operates on a one-vote-per-country basis, the historical predominance of OECD countries in the ITU has thus dramatically changed at a time when the level of technical complexity has greatly increased. Further, the global view of telecommunications has shifted, with modern communications being increasingly recognized as a primary strategic and economic force in today's world.

At the last major World Administrative Radio Conference, held at Geneva in 1979, the ITU's radio regulations were reviewed and extensively revised. Certain issues, however, were not resolved and led to the adoption of a resolution (No. BP-1) to hold two conferences (now scheduled for 1985 and 1987) in order to determine the means whereby all countries of the world could be guaranteed equitable access to the geosynchronous orbit for purposes of satellite communications. Preparations for these major conferences have already begun in earnest in the United States and elsewhere. In the United States, for instance, an advisory committee of experts, with over 100 members and a network of subcommittees, is hard at work developing positions, strategies, and evaluations of options. U.S. governmental staff (particularly in the Federal Communications Commission, NASA, the National Technical Information Service, and the Defense Department) as well as consulting firms are engaged in technical studies, while the U.S. State Department is undertaking preliminary soundings around the world.

Although the U.S. preparations are perhaps the most complex, a somewhat comparable level of activity has also begun in most OECD countries. The level of detail involved is great. In Japan, for example, the National Space Development Agency is developing technical/legal proposals concerning procedures for removing retired communications satellites from geosynchronous orbit. In the United Kingdom, a sophisticated study of the relative merits of using lasers instead of microwave for space-to-earth energy relay has been undertaken.

The Pivotal Issues

Although there are hundreds of technical subjects to be evaluated, discussed, and agreed on at the 1985 and 1987 WARC meetings, the basic policy issues are small in number. There are, in my view, three pivotal issues, which, perhaps surprisingly, are heavily dependent on technical reasoning and studies.

First is guaranteed access to the geosynchronous orbit. The developing countries will likely press for a standardized planning formula of dividing the "orbital arc resources" equally among all countries, regardless of need or ability to use the orbit in the near term. The idea is to protect the "resources of geosynchronous orbital space" for the future. From the developed countries will come alternative proposals—and some of them will be quite innovative, including the following ideas:

- Division of the orbit into broad geographic "regional service sectors," aimed at accommodating regional demands.
- Establishment of interim or short-term procedures to continue first come, first served principles, with penalties or sanctions for overstaying allocation periods.
- Various economic/technical/operational plans to guarantee access to the orbital arc for developing countries, either by tighter spacing of satellites in order to accommodate newcomers or by providing firm commitments that multilateral/multiuser satellite systems such as INTELSAT will provide space-segment facilities and services adequate to meet Third World communications needs. This last might be achieved either through long-term lease of a space segment or through dedicated space segments as provided for under Article 3(e) of the INTELSAT Agreement.

In fact, the final solution might be a combination of these proposals, since a continued INTELSAT policy of leasing capacity for domestic services can be anticipated even in the absence of the WARC negotiations.

The second pivotal issue is defense and governmental versus civilian or commercial applications of space. Radio location (radar) and, to a lesser extent, military space communications, are applications where exclusive use of frequencies is desirable. The parallel growth of defense and commercial/civilian space communications during the 1970s and early 1980s increasingly means that these two types of services (i.e., military and civilian) are in direct competition for radio allocations in the geosynchronous orbital arc. The escalation of this battle, particularly when viewed as a zero-sum game, translates into a difficult, troublesome series of issues to resolve with only a minimum of positive answers in sight.

Small, conventional dedicated communications satellites, versus large, technically complex multi-frequency space platforms or clusters, constitute the third issue. The demands on the geosnychronous orbital arc can be resolved in only a few ways: by limiting the growth of services; by using tighter spacing of satellites with more interference; by using either more efficient modulation, coding, and processing techniques, in order to allow higher throughput in the same satellites, or higher-performance spacecraft, such as large, multibeam orbital antenna farms or satellite clusters, in order to allow manyfold frequency reuse and multipurpose service at a single point on the geosynchronous orbital arc. It is of course possible—indeed likely—that all of the above could happen simultaneously. Philosophically, though, the basic issue has to do with the balkanization of space

through the proliferation of dedicated satellites versus integration of space applications into multipurpose and multiuser programs.

Today, the trend is toward continued satellite proliferation, with each country (indeed, each company or institutional entity) trying to plant its flag or corporate logo in Clarke Orbit. To state the extreme, if each communication satellite system identified for operation by 1985 were to be used as a trend line for projecting the situation in 2025, one could project some 20,000 separate satellite systems! Although this is clearly an impossibility (only some 120 to 180 orbital slots are available in the Clarke Orbit), the planners of satellite services have yet to face the need to consolidate domestic services in a manner similar to that which INTELSAT has done internationally.

Despite the complexity of the issues involved and the many technical, operational, financial, and industrial issues that the use of the geosynchronous orbital arc have generated in the past twenty years, there is no reason for despair. Indeed, for the following reasons, there is a sound basis for optimism:

- *A Strong Motivation toward Research and Development.* The challenge of fiber optics, the demand for new satellite services, the growing revenues from satellite communications, and the tremendous demands upon the Clarke Orbit all stimulate a strong R&D effort to provide new and more cost-effective technologies. Progress in the field since 1965 has been enormous—a result largely fueled by R&D. The prospects for the future are equally bright.
- *Technological Solutions on the Horizon.* A number of technical solutions that can multiply the effective use of the Clarke Orbit are almost within reach. These include on-board signal processing; large, multibeam antennas to allow extensive frequency reuse; space platforms; satellite clusters; and intersatellite links. These technologies should allow an increase of the effective capacity of the world's satellite systems by more than one-hundredfold by the twenty-first century.
- *Workable Institutional Arrangements.* The institutional arrangements within which decisions concerning satellite communications must be made are complex and intimidating to the uninitiated. They are, nevertheless, quite workable. Although improvements might be possible with regard to the structure and operation of the ITU, the IFRB, the CCIR, CCITT, INTELSAT, INMARSAT, and the IPDC, by and large these institutions are coping with significant telecommunications issues with considerable skill and success. The world's telephone and data network is today one of the largest and most smoothly functioning machines known, and the implication of the so-called Integrated Services Digital Network (ISDN) in the 1980s will make it even more so. This amazing achievement is, in part, a testament to the institutional arrangements in this field.
- *Effective Leadership.* Knowledge, competency, and capable administration, rather than political charisma, remain the key assets of leadership in the field of international telecommunications. The secretary general of the ITU is a capable person.
- *A Spirit of International Technical Cooperation.* The UN systems have at times seemed to have fallen victim to petty politics, bloc voting, and endless, unresolved debate. It can be confidently said, however, that the ITU has for the most part escaped these pitfalls. A telecommunications tradition of more than 100 years remains strong; issues are generally examined on their technical merits and are objectively assessed. Peer pressure among scientists and engineers to exclude polemics and to seek sensible and equitable solutions has served telecommunications the world over quite well. One can hope the tradition will continue.

As we reach into outer space to seek better ways to serve the people of our small planet, we also see the extent to which we are committed to a common goal and a common fate. Our earth is only a 6-sextillion-metric-ton mudball—a small planet in a small solar system, on the outreaches of a medium-size galaxy, in a universe studded with hundreds of millions of other galaxies. As we gain this cosmic perspective, the desirability of finding global solutions—not only for telecommunications problems but in all fields of endeavor—will become increasingly clearer. In the field of satellite communications, certainly, the sky is not the limit.□

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Joseph N. Pelton is executive assistant to the director general of the International Telecommunications Satellite Organization (INTELSAT). He has worked in the field of satellite applications since 1965, with North American Rockwell, NASA, George Washington University, the Communications Satellite Corporation, and INTELSAT.

Pilots of Outer Space

B.J. Bluth

Imagine spending six months in a moderate-size motor home, traveling across the United States. You don't have to drive. At the same time, you can't get out and go for a little stroll by yourself. The view is matchless—270 miles straight down to earth and a sunrise or sunset every 90 minutes. The company, however, stays the same day in and day out.

This experience of long-term spaceflight is becoming routine. The Soviets have had three long missions lasting between six and seven months. There is a prime crew of two men, with teams of two or three visitors (one was a woman) who come and stay for a week or ten days. The longest U.S. flight was the eighty-four-day Skylab mission, which ended in 1974. Both countries have plans for more ample stations prepared to hold larger crews. The longer the missions, however, the more difficult the interpersonal, social, and psychological factors become. Valery Ryumin, who has been on two six-month flights, put it this way in his diary:

> Our problem is deeply human. We must now adjust to living together, away from the rest of the world. Robinson Crusoe, after finding himself alone on an uninhabitated island solved problems by himself, accounting to himself. We have to solve ours together, taking into account the feelings of the other. Here we are totally alone. Each uttered word assumes added importance. One must bear in mind—constantly—the other's good and bad sides, anticipate his thinking, the ramifications of a wrong utterance blown out of proportion.

He added that he thought one of O'Henry's comments fit the situation quite well: "All one needs to effect a murder is lock two men into a cabin, 18 feet by 20, and keep them there for two months." There have been no murders yet, but there have been problems.

Generally derived from Talcott Parsons' General Theory of Action, six factors can be used to study the situations and problems that have developed in spaceflight:

- *Environment*. The space environment itself, especially its weightless condition, can affect the way a crew member works and feels. Besides weightlessness, it includes such items as cosmic radiation, isolation, confinement, architecture, technology, tasks, ground control, and the outside world of service, family, friends, other groups, and events. This category also includes equipment design and human-machine relationships.
- *Physiology*. Living in the space environment, a crew member experiences significant bodily changes that affect many of his sensory systems as well as physical, and hence mental, tone. This includes the impact upon the skeletal, muscular, and cardiovascular systems. Space sickness (though it does not usually last beyond seven days) is a good example of impaired effectiveness in the space environment. Other factors that may affect human mental tone by way of physiological changes are related to type or availability of food or to ingredients of the life-support system.
- *Personality Systems*. Individual predispositions of cognition, attitude, motivation, values, and thinking patterns can contribute to error and poor adaptation. Since an individual is not static, but changes in both predictable and unpredictable ways, selection is a useful (but not sufficient) facet of personality evaluation.
- *Social Systems*. The design or organization of systems of authority, roles, schedules, communication patterns, decisionmaking, leisure activities, jobs, and informal interaction is related to the way in which a crew performs its duties, both on the station and vis-à-vis the ground. This category includes systems of rewards and career advancement, manipulation and interchange with and within the environment, social control, and socialization processes.
- *Culture Systems*. Ideas, values, beliefs, assumptions about what is good, bad, important, and real constitute an ongoing background factor in crew activity and in ground-crew interchange. Culture systems have an important effect on performance and expectations.
- *Process*. Events occur in sequences or interrelated strings, becoming unique configurations which form growing cumulations of significance as time passes. A given event, out of context, may seem unimportant but, seen within the context of its total historical progression, can become a matter of great importance.

Furthermore, there is constant interchange with many environments: the technical, immediate interpersonal, and that between the ground and orbiting crews, including families, friends, and the general effect of worldwide events.

Close Calls

Both the American and the Soviet space achievements have been impressive, amply demonstrating the ability of people to live and work successfully in the unique environment of space. However, both programs have also had their share of problems that can be traced to social and psychological factors.

Two missions of approximately six months duration and one of almost seven months have been flown by Soviet cosmonauts in the Salyut 6 and 7 space stations. Prior to each Soviet mission, extensive tests and activities are undertaken by the Group for Psychological Support to ensure the compatibility of the crew members and provide training for the flight. Crews undergo a rigorous program designed to develop self-confidence and emergency survival skills. During each mission, the group constantly monitors the crews to detect signs of stress, and it is responsible for developing compensatory measures. Despite all these precautions, General G. Beregovoi, chief of crew training, reports that crews developed signs of interpersonal hostility about thirty days into the mission and that this situation is a matter of concern, with respect to both flight safety and mission effectiveness. This problem is confirmed by other cosmonauts. Cosmonaut Sevastyanov commented that "joint existence cannot be serene. We had disagreements in flight. . . . The disagreement did not reach a scandal, inasmuch as there was no 'platform' [it would be very hard to "punch" someone is weightlessness]. It was simply fatigue, and frequently simple inattention, which could cause the argument." Cosmonaut Lenov remarks that "the effect of psychological compatibility arises after approximately one month of staying under conditions of group isolation. The longer the flight, the more strongly the given effect appears." Lenov concludes that, despite preparations and training, "it is impossible to ensure good psychological compatibility on a long flight," and there are rumors that Cosmonaut Ryumin wanted to return to earth a couple of months into his second long flight. Soviet scientists have speculated that this problem is caused by exhaustion of the nervous system, the biological toll of weightlessness, informational overload, and constant publicity. However, other studies of Soviet systems suggest that social and cultural system variables are important contributing factors.

The hostility that has appeared in Soviet missions is not confined to the flight crews. There also have been arguments and conflict between the crews and the mission control staff on the ground. One cosmonaut commented that sometimes crews were happy in "autonomous flight without communications from earth. To be alone without constant nitpicking from the earth was sometimes necessary." The crews were reported to have masked their feelings and reactions, withheld information, and on one occasion were rumored to have turned off all communications with the ground for two days.

Crews show mood swings, increases in tension, and difficulty sleeping. They are apparently reluctant to use the games provided by the Group for Psychological Support for relaxation, and often use their leisure time to work. "Rest and work in space have different meaning," according to Cosmonaut Kovalenok. In space you want to "load yourself with work so the time will go faster. Otherwise, you feel that the time slows down, and then you feel the loneliness, or you start thinking of aches, pains, sinus congestion, or your general physical condition." Lack of work to do is related to psychological conditions that, Kovalenok says, are "particularly severe under zero-gravity conditions." In space, a man is in a state of "constant alertness."

Exuberance nearly resulted in tragedy for the Soviet program when Y. Romenenko supposedly forgot to attach a safety tether as he took an unauthorized look outside his Salyut-6 space station. When the rookie Romenenko and the veteran Grechko arrived on Salyut 6, one had to make an early space walk to check the docking port. There was some fear that the automated Progress resupply ships might not be able to dock at the station, possibly forcing the crew to return to earth. Grechko went out into space, and Romenenko was suited up in the airlock, responsible for watching Grechko's life-support systems. Romenenko had heard how beautiful space can be—stars like jewels sparkling on black velvet; colors so beautiful that no photograph could reproduce them. The story goes that the excitement got to him and that he decided to take a little peek—to pull himself up just enough to put his head out the hatch for a look. But as he pulled himself up, his momentum in weightlessness took over, and he floated out. He had not secured his safety tether and soon found himself flailing about, gradually floating away from the spacecraft. Fortunately, Grechko saw him and grabbed his foot. It was more than a close call.

Soviet cosmonauts, like their American counterparts, are trained to follow checklists and to comply with safety requirements without fail. Such a lapse of judgment was a serious mistake—one that is perhaps even more important than Romenenko's small adventure, as it raises questions about the way some people may react in space.

V. Vereschetin, a deputy chairman of the Intercosmos Council, stated at a Moscow news conference that "cosmonauts' efficiency declined during long flights." Cosmonaut Ryumin (who was on both long flights) believes man could stay up longer, but was quoted in *Izvestia* (March 28, 1981) as saying that "after 3-4 months of work in orbit, exhaustion sets in. And if there is not a special need for some sort of very important task, there is no particular sense in pushing a cosmonaut's body to its endurance."

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At a recent conference in Bonn, West Germany, the academician Gazenko reported that "psychological and everyday-life discomfort . . . seems to be inevitable for space operations for the near future," and thus the "duration of space missions may be dependent on nervous-emotional stability of crew members, their psychological compatibility, level of motivation, pattern and stability of various habits, and other factors that can hardly be identified." The question to be asked here, however, is why cosmonauts become fatigued, what affects their stability, and which factors can be identified and changed.

> "All one needs to effect a murder," said O'Henry, "is to lock two men into a cabin, 18 feet by 20, and keep them there for two months."

A number of accidents, near accidents, and problems have also occurred in the American space program. One very nearly fatal incident came about during the Apollo-Soyuz test project as the command module reentered the atmosphere. There had been a number of cockpit errors on this mission, and these included forgetting to set two critical switches for reentry which would have prevented automatic devices from deploying the chutes and from dumping excess fuel and oxidizer from the attitude-control rocket engines. Commander Tom Stafford apparently was distracted and neglected to call for them at the proper time, and the rookie astronaut, Vance Brand, also missed them. As the capsule reentered the atmosphere, the crew began to choke, gag, and gasp as highly corrosive nitrogen oxide gas filled the cockpit. Brand passed out cold, and it took five minutes for Slayton and Stafford to break out the oxygen masks. The effect of such a toxic mixture on the lungs could have been fatal.

In evaluating the reasons for this error and the others that occurred, Astronaut Walt Cunningham suggested that Stafford and Slayton had not trained as much as they should have for the mission and that "the crew did less training *together* than usual, even for those phases of the mission which required close coordination." He cited a heavy social schedule, emphasis on public relations, and the fact that much of the training load was placed on the rookie's shoulders. There was a significant status difference between Slayton and Stafford, on the one hand, and Brand, on the other. Deke Slayton and Tom Stafford were veterans of the U.S. space program and had many years of experience and high positions in NASA. Brand was young and new. This accident was not caused by equipment failure, but by human error, conditioned by social system factors in conjunction with personality and cultural factors. The value placed on social and political activities superceded the need for training, and the influence of status may have inhibited communication between Brand and his superiors.

Scheduling and time pressure are cited as some of the major causes of error on the 1973/74 Skylab-IV mission, which lasted eighty-four days. Since this was to be the last mission for Skylab, many new experiments were added to the flight plan. The crew had not trained for these experiments, however, and it took longer than expected to set up and carry out the new experiments. There were many unanticipated difficulties, yet the ground pressed the crew on in order to take advantage of the precious time in orbit. As a result, the harried crew was plagued by errors, mistakes, and lost data. The problem got so bad, in fact, that Commander Jerry Carr asked Mission Control to have the ground staff completely rework the program, giving the crew more discretion to do their own scheduling from a shopping list of experiments as well as more time to themselves. Once this new system was instituted, the crew's performance improved considerably.

Unique to Space?

Early studies of the social and psychological factors involved in long-term spaceflight started with the assumption that the symptoms, errors, and accidents that occurred were primarily related to the biological ramifications of weightlessness or to the phenomena of isolation and confinement. Symptoms found in either Soviet or American spaceflights included insomnia, irritability, mood fluctuations, fatigue, hostility, vacillating motivation, depression, and stress—symptoms quite similar to those found in isolated and confined environments. However, the list of symptoms that emerged in spaceflight also has much in common with the list of symptoms that develop in environments which are not isolated or confined, but which are associated with the development of stress. Although some spaceflight symptoms can be traced to the effects of weightlessness on the body (these vary in intensity as the body adjusts), there are other systems which can be related to the structural aspects of stress in general and, as such, are subject to alteration.

Environments studied by NASA in the 1960s and considered to be isolated and confined included the Antarctic, submarines, oceanographic research vessels, undersea habitats, simulations, and fallout shelters. NASA itself sponsored many simulations as well as undersea expeditions in order to study the features of isolation and confinement. The symptoms that can be extracted from that literature are as follows: boredom, irritability, depression, anxiety, mood fluctuation, fatigue, hostility, social withdrawal, vacillating motivation, tension, sleep disorders, and lowered performance. Studies made of the stress literature yield the following list of symptoms: boredom, irritability, depression, anxiety, excessive emotion, anger, tension, sleep disorders, lack of concentration, lowered efficiency, defensiveness, and fear.

This research traces the causes of the symptoms to many different sources, many of which can be related to spaceflight situations. Some of these sources are: conflicting definitions of a situation, mismatched work, organization, leadership systems, scheduling, expectations, group size, reduced roles, reduced sensory input, architectural arrangements, group composition, training, communication systems, physiological factors, crowding, loneliness, career development, job design, time pressures and long hours. These studies suggest that many of the symptoms that develop on long flights may not be unique to the space environment and, in fact, may be alleviated by training and careful design of social and environmental features. A few examples from this vast literature follow.

Weightlessness brings about profound changes in the human body, and there should be no discounting the potential impact those changes can have on the psychological readiness of a space station crew. Earthbound studies, however, show that people can mistake socially or psychologically created tension as a biological problem. For example, fatigue and sleep disorders are often a symptom of social or psychological stress. Continued disruption of the sleep cycle increases fatigue while increasing general tension and thus inducing more strain into the situation—a vicious circle.

A recent NASA report also shows that there are clear psychological effects from the alterations in circadian rhythm and the rapid changes from light to dark that occur in orbit. These symptoms included depression, hopelessness, boredom, irritability, negative moods and withdrawal, fatigue, decreased performance, insomnia, anxiety, as well as gastrointestinal and other physical symptoms.

Social and psychological conditions are important with respect to establishing good group relationships. Normally, for example, a person's involvement in a group represents but one facet of his life. There are many groups, many roles, many spaces between groups, and thus many outlets for interests and support. A work group in which one is constantly evaluated is distinct from the family or friendship group, where the individual believes he is accepted and wanted for himself. Ideally, he does not need to be on guard, to prove himself, or to put forth his best effort. As part of a space crew, one combines work and informal life, and all aspects of daily life are carried out in the presence of the same group of people. One is never alone. The "boss" is always nearby. Such a situation automatically places a strain on the crew members because the same group must carry out two different and incompatible functions: work and friendship, evaluation and nonevaluative support. In a space station, there is an additional strain: the situation is potentially dangerous, and survival depends on interdependence. Research shows that such a situation can bring on fatigue, headaches, poor communication, and problems with authority.

To cope with this problem in its two-cosmonaut crews, the Soviets have almost completely abandoned formal hierarchical roles between the crew members. The Americans do have clear hierarchies in place for the space shuttle missions, though it is questionable how salient they are now, since these people have worked together for so many years that they do not depend on formal role structures in their interactions.

There is evidence that groups having an even number of members behave differently from groups having an odd number of members. Even-numbered groups disagree more than the odd-numbered ones and, as a result, suffer more deadlocks. Groups having an even number of members may split into equal factions, which does not usually happen in a group having an odd number because one side always has the numerical advantage. Groups of five usually escape such divisions and are shown to rate high in member satisfaction; dissenters have some group support. As the group gets larger there is more stability, but the lines of communication tend to become focused on the leader, some members becoming more passive. When these groups are total systems, with work and primary relationships being coextensive, the deadlocks, disagreements, and tendencies to soften rules or circumvent the command structure become much more important. Such situations can become a source of strain and error-producing conditions. By keeping groups in odd numbers, some structural generative elements of stress can be avoided.

In space, rest and work have a different meaning. One is in a state of constant alertness.

This seems to have been confirmed in both the Soviet and the American experience. The Soviets, with their crews of two, seem to have had more interpersonal problems than the American crews of three—a result that was predicted in the early 1960s by NASA researchers.

Newcomers into small, cohesive groups often complain of being shut out. A basic trait of group membership is the feeling of togetherness, belonging, and a sense of "us" as opposed to "them." The identity of the group becomes defined by its *distinction from other groups*; out of a desire to preserve this identity, groups often will forget internal disputes while confronting "outsiders." In fact, this phenomenon is often used to provoke internal group cohesion and loyalty.

Some discomfort has been reported by non-Soviet cosmonauts who have visited the Salyut station under the Intercosmos program. The Czech cosmonaut, Remek, reported feeling uncomfortable and left out on occasion.

There were misunderstandings, hurt feelings, and a genuine concern about the problems of language and communication.

Thus, by rotating station crews—one half leaving and the other half staying—two distinct, and possibly antagonistic, groups might be created. If schedules should further tend to isolate the two groups, living and working in small quarters, the potential for distrust, suspicion, and hostility is increased. There may be many unexpected problems if the crews are mixed cultural subgroups or come from multinational backgrounds.

Research has shown that organizational structures should vary with the demands of the job. Jobs involving research require a more open-ended, loosely structured system. Jobs that demand on-site problemsolving require flexibility. And jobs that are precisely defined and broken down into small divisions of labor demand a high level of structure. The formal aspect of an organization (the fit between the task and the normal practices of the organization) must match the climate of the organization (the subjective perceptions people have about the organizational setting). These can be compared on predictable and unpredictable dimensions. Thus, predictable tasks call for a predictable climate, and unpredictable tasks call for more fluidity or flexibility in the climate. On Skylab, however, many unpredictable jobs were scheduled as though they were highly predictable; this created stress for the crew and tension between the crew and the ground personnel who were responsible for the planning.

Numerous studies have also shown that mental health problems, stress, and alcoholism are related to a lack of participation in decisionmaking, a lack of control over the work, or a lack of autonomy. Stimulating some internal regulation of the system by the group, using discretionary rather than prescribed work roles, increasing variety, and decreasing the bureaucratic mode—while keeping in mind the fact that the primary function of these groups is to work—have resulted in significant increases in effectiveness and a decrease in stress-related problems. When Skylab crews were given more control over their schedules, their productivity improved significantly.

A look at some of the problems that developed on the Skylab suggests that a different work design might have reduced some of the difficulties the crew experienced. There were also disagreements between the "scientist astronauts" and the "test-pilot astronauts" during the Apollo programs, resulting in lost, damaged, or eliminated experiments. Such subculture differences could also be a problem on long-term missions if the organizational and decision systems are not designed to recognize the varying assumptions, values, and requirements of the different groups.

Architectural research shows that the design of workspaces and living quarters can have an important effect on mental state. Astronauts and cosmonauts have commented on the use of color (they do not like what is there), windows (there are never enough), noise (there is too much), smells (there are not enough good ones), flexibility in arrangements (one cannot change things), restraints (there are not enough places to put things, and things do not stay put), good traffic flow, organization of public and private sections (there is no place to be "alone"), and the inclusion of "nice" touches such as fish and plants.

Studies show that the sociotechnical design of work stations needs to fit the kinds of mental models needed to operate the facility efficiently under routine as well as emergency conditions. These studies are proceeding in the design of aircraft cockpits, nuclear power plants, as well as computer terminals and general areas. Analyses of space shuttle and Skylab equipment suggest that some design features are conducive to human error or create difficulties in weightlessness.

Different Strokes

The United States and the Soviet Union have completely different approaches to the problems discussed above. In the early days of the U.S. space program, there was considerable concern about the possible psychological effects of space. Numerous tests, studies, and reports followed. Space did not turn out to be as mentally debilitating as was feared, however, and as the astronauts acquired the ability to fly spacecraft instead of just ride them, they also edged out the psychologists and their programs. They seem to have had good reason to do so. Stories and reports suggest that the psychologists were not very sensitive to the feelings and attitudes of their subjects, and that their suggestions were often seen by the crews as too theoretical and lacking in practical application. The result was that no systematic psychological studies were made of the Apollo or Skylab crews, or of the conditions on board the spacecraft that related to mental state, error, and so forth. Psychological studies dropped off dramatically, but did not stop. NASA continued to sponsor university research—work on the kinds of conditions that develop in confined microsocieties, a management study of a spacelab simulation, evaluations of undersea conditions and their effect on mental and interpersonal activities, and some situation studies of oceanographic research ships as well as of male/female crews on supertankers. The results of these studies, however, were not filtered into the design process at NASA and hence have had little impact on flight programs.

Now that NASA is looking seriously at the development of a space station within the century, people in the agency are beginning to look seriously at the social and psychological problems involved in long space missions. Some small studies are being done in-house and by industry, including research on the command and control of varying numbers of mixed crews, work and rest schedules, the influence of diet on astronaut mood and performance, and the impact on humans confined to small quarters and remote locations. Also reported to be in the offing is a review of past work in the behavioral

sciences, in order to identify research gaps and plan the steps that should be taken next.

The Soviets have been deeply interested in the psychological aspects of space flight since the inception of their program, and they have a strong and vigorous approach to this facet of spaceflight. In fact, the Soviets state quite clearly that long-term spaceflight is highly dependent on the psychological state of the crew, and that they are taking every possible measure to ensure a good mental state in their cosmonauts. They engage in research, testing, training, in-flight observation and troubleshooting, and postflight evaluations.

The Group for Psychological Support does much of this work, and it is supported by programs under the head of crew training, General G. Beregovoi. For example, the group is constantly performing sophisticated voice-stress analysis while the crew is in space. When high levels of stress are indicated, or are growing, the group arranges interactive television meetings with family, friends, famous people, and the scientists involved in the experiments the crew is conducting. They have arranged for surprise packages to be delivered in the Progress resupply ship in addition to special foods, fresh fruit, letters, video movies and special programs, gifts, and even a guitar. One goal of the Intercosmos program, which has brought cosmonauts from many non-Soviet countries to spend time at the space station, has been to break the boredom, monotony, and loneliness of crews on very long missions, not just meet the technical goals. "Parties" are planned with ritual salt and bread, the customary foods of the visitor's country, and so on. The Salyut-7 spacecraft, moreover, included changes in color scheme and design to make life on board more pleasant. Under General Beregovoi, all cosmonauts go through a rigorous training program intended to develop self-reliance, self-control, self-confidence, and the ability to keep calm and alert in an emergency.

Despite all of these efforts, however, the Soviets still report problems. They state publicly that they have not developed adequate methods for establishing compatibility between crew members and that much is still done on a commonsensical level. The Soviets are also showing serious interest in the relationship between the biological effects of weightlessness and the potential impact on moods, attention, and motivation.

The overall Soviet approach seems to be one of providing the crew with a variety of possible alternatives—skills, knowledge, and psychological training—for coping with long-term space sojourns. The Soviets assume that man is not limitless in his capacity to adapt, and that success demands a good understanding of strengths, weaknesses, and boundaries so that man and environment can work synergistically. To leave the human element—one of the most important factors in the "loop"—to chance or "common sense" seems to them to be an unscientific approach.

It is very difficult, I should note, to evaluate Soviet materials, even when they are available. The Soviets have a different approach to the treatment of data then those trained in the West; thus, they do not include information that might be thought necessary from our point of view. What is seen, however, seems to be heavily oriented to the biological and psychological questions, with little emphasis on social systems. Cosmonauts seem to be looked at from the psychological perspective and not as members of a complex system of social layers and group dynamics. Again, though, this may not be the case. The Soviets claimed quite vigorously that they were not planning to send any more women into space for quite a long time and for many reasons—but then Svetlana Savitskaya was placed aboard the Salyut 7 in August 1982.

Spaceflight experience (especially by the Soviets on very long missions), together with data from isolated, confined, and stressed populations, shows that the longer a flight, the more critical social and psychological factors become to flight safety and mission effectiveness. This experience also shows the importance of the human factor in space. As spaceflights continue, the involvement of practical behavioral sciences will no doubt increase, giving rise to unprecedented opportunities for applications and research. Space stations are natural laboratories. Situations are real, yet groups are small, making it possible to manage the information. Crews may be willing to try different social systems and thus provide an opportunity—in isolation from the interfering variables that plague earth-based research—to learn a lot about fundamental social processes. The frontiers of space are also the frontiers of social science.□

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B.J. Bluth, professor of sociology at California State University-Northridge, has also worked with the NASA Space Station Task Force. Her writings have appeared in such disparate publications as Teaching Psychology *and the* Journal of Mechanical Engineering.

Little Green Men and All That

Ron Westrum, David Swift, and David Stupple

The idea of a plurality of inhabited worlds is indeed an old one, having inspired and troubled man since ancient times. Whether man is alone in the universe, whether there are other worlds with intelligent beings on them, possibly superior to us in knowledge, are questions that have long exercised our reason and our imagination. With the development of modern space technology and radio astronomy, we have taken the first steps to explore nearby worlds directly and to scan far-off ones for signals from intelligent life. Our civilization is now at the stage where we have not only evolved sophisticated ways for thinking about extraterrestrial intelligence (ETI), but have also developed means for detecting and communicating with such intelligence. Yet the technical feasibility of detection and contact must confront questions of broader social policy. How much money is to be spent on such searches? Who will be responsible for carrying them out? What kind of searches should be carried out? To date, no searches for electromagnetic signals have been positive. Are further searches worthwhile? What kind of attention, if any, should be given to investigating UFO sightings, whose reported strangeness would seem to suggest extraterrestrial origins?

Whatever decisions we as a society make on these issues in the long run, the concept of ETI is affecting our society in many ways—through science fiction books, films, and television programs; with respect to our religious beliefs; through public interest in the space program; and in regard to our self-image as unique beings in the universe. Our children play with toy rocket ships and models of E.T. This response to the idea of ETI strongly reflects the hopes and fears of our society about its own future welfare.

Our purpose here is to examine American society's response to the ETI concept. To do so we have chosen three subcultures in American society whose existence is based on the idea of extraterrestrial contact. The first subculture consists of *religious groups* which believe that contact is now taking place and that messages from "space brothers" have already been given to human beings. The second is made up of groups and individuals who investigate UFO sightings, the "*UFOlogists*." The third subculture consists of *scientists* who are actively involved with research and thinking about intercepting signals from extraterrestrial intelligent species. Each of these subcultures believes that ETI exists and that it is making active efforts to contact us. Apart from this assumption, though, the membership, social structure, norms, and intellectual underpinnings of these groups are quite different. Each tends to regard the others with indifference or even scorn, in part because of differences in style, methods, and membership, but also because they represent three competing responses to the same basic idea.

If there are people on other planets, then why can't they come here? And if they do come here, then why don't they land on the White House lawn? Might they pick a humble person to communicate with? After all, didn't God pick Jonah to deliver one of his messages?

This basic premise, that extraterrestrials could arrive on earth and communicate with ordinary people, underlies the entire "contactee" subculture we are about to examine. It provides a rationale for individuals who have had "contacts" to speak publicly about their experiences, for others to elaborate doctrines based on such experiences, and for the formation of organizations to collect and disseminate such testimonies and doctrines. The inherent interest in such testimonies (if true) and the vividness with which they are related also allow for their exploitation by the mass media—particularly by radio

and television talk shows. No matter how implausible the basic premise might seem to others, there is no question that, for millions of Americans, this premise not only made sense but seemed to have been proved correct by the testimonies contactees gave about their meetings with the "Martians," "Venusians," or whatever. Today, there are hundreds of small religious groups in the United States which believe that extraterrestrials are in contact with earthlings and that they wish to help us.

> If there are people on other planets, some say, then why can't they come here. And if they do come here, then why don't they land on the White House lawn?

George Adamski was the first of the contactees. In 1952, at age 61, Adamski claimed that he had a meeting with Orthon, a man from Venus, near Desert Center, California. Before his experience, Adamski had been a handyman and an undistinguished teacher of "metaphysics." He was also interested in photography and had previously produced pictures of UFOs, later labeled fraudulent by the Air Force. In 1953, in a book published with the British writer Desmond Leslie, *Flying Saucers Have Landed*, Adamski gave the first of many accounts that he and others were to offer of meetings with extraterrestrials. Other contactees, among them Truman Bethurum, Orfeo Angelucci, Howard Menger, and Daniel Fry, rapidly gave their own accounts of such meetings and of the behavior and message of the "space brothers." How sincere they were is open to question. Adamski, Menger, and Fry were caught in falsehoods, and others were very suspect, but their "messages" had effect.

The contactees were a predictable attraction for radio and television talk shows; Long John Nebel, Betty White, and Steve Allen all featured them. The 1950s were a time when the threat of atomic war seemed very real. For many people, it must have been comforting to believe that benevolent intelligences from other planets were watching over them and that they were communicating messages of warning and hope to earthlings who would then pass them on. Furthermore, such accounts were intrinsically exciting, if improbable. The media found in the contactees an easy way to exploit the high public interest in flying saucers. The contactees themselves basked in the attention, and proceeded to translate it into invitations to speak at "platform societies" and to found their own "flying saucer clubs."

Platform societies sponsor a succession of speakers on topics relating to psychic abilities, religion, spiritual healing, mysticism, and similar matters. Such groups sometimes sponsor psychic fairs, where local practitioners exhibit their skills in astrology, tarot reading, and various practical parapsychologies. They also may offer courses in the "mystic arts." The members of platform societies, contrary to an influential study published in 1966 in this magazine, are *not* society's marginals, the elderly, infirm or unadjusted who "cannot carry on a conversation." Religious scholar J. Gordon Melton, familiar with many of these groups, suggests that their members are "ordinary people with some extraordinary beliefs." Although many of them are well educated, they tend to be uncritical. They accept each speaker as having, in their words, "part of the truth." In Detroit, a common metaphor compares rival esoteric systems to looking at a house through different windows; each has its own view of the same room. The contactees, whose stories of exotic contacts with "space brothers" fit easily into the framework of these groups, became popular speakers for them. The attention they received, moreover, allowed the contactees to develop their own groups, and many of their disciples learned useful organizational techniques from participation in the platform societies.

From about 1954 to 1959, the flying saucer clubs became a major vehicle for the organization of people interested in the religious aspect of extraterrestrial contacts, and they were reinforced by a succession of newsletters, magazines, and articles devoted to flying saucers and their ostensible occupants. By the late fifties, the contactees' popularity was eclipsed by the growth of the publishing industry which had developed to promote them and the idea of flying saucers. *Fate*, a popular magazine devoted to the occult, found that publishing flying saucer stories helped its circulation immensely. One of its editors, Ray Palmer, left *Fate* and founded his own magazine, *Flying Saucers*, which was strongly dependent on the contactee and "UFOlogy" subcultures. Another publisher, Gray Barker, got his start in the business through a "creature story" published in *Fate*, and he went on to write *They Knew Too Much about Flying Saucers* (1956), the book that first described the "three men in black" who threatened witnesses. The men in black were to become a staple item of UFO lore. Barker eventually set up the Saucerian Press, which continues to publish books oriented to contactees and the more exotic aspects of UFO folklore. Barker's mailing list now includes 4,500 names, mostly people oriented to contactee themes rather than to occult or metaphysical ones, according to evidence from a reader poll. As the popularity of the better known contactees waned, these publishers became celebrities themselves, often in demand on the lecture and convention circuit.

But the 1960s witnessed the decline of the flying saucer clubs and the fragmentation of the contactee subculture into a large number of only loosely related segments. The most easily identifiable groups are relatively large and organized charismatic congregations, such as

George King's Aetherius Society, and are dependent on a single figure for leadership and prophetic messages. The Aetherius Society has perhaps 1,500 members in the United States and England. On a similar scale are psychic groups, such as Ruth Norman's Unarius Foundation in California, that often have substantial mailing lists and for which extraterrestrial contact is an important topic of interest. Nonetheless, there is a larger number of small groups whose members are also interested in hearing about messages from space. These include the platform societies as well as smaller groups organized for discussion, reading, and sometimes projects related to contact ideas. One such group was building a large "flying saucer" that, it was believed, would one day fly. Several highly skilled members of the group worked on making the vehicle structurally sound (the propulsion unit was to be supplied by the extraterrestrials). The group seemed to exhibit a working-class culture of recreational excitement, and much of the group's attention was focused on the physical task of getting the saucer built.

These diverse contactee groups also share several literatures, including books on contact experiences, astrology, psychic science, "metaphysics," nontraditional healing, and various forms of self-help. Much of the contactee literature has a "new age" emphasis, in many ways paralleling the Age of Aquarius theme in the youth movements of the 1960s. Much of it contains a millennial message suggesting that the space brothers are soon going to intervene and help mankind in various ways. Much of it, in other words, contains "good news for Spaceship Earth" from the extraterrestrials, who are usually described as wise and benevolent. The literature also contains a contactee folklore, mostly manufactured by the writers and publishers. The literature, its personalities, and its folklore provides the thread that ties together (very loosely) the contactee subculture.

Today there are hundreds of small religious groups in the United States which believe that extraterrestrials are in contact with earthlings.

In sum, the contactee subculture, born in the 1950s, is now maintained through an extremely diverse set of groups, some of which are organized as religious sects or as contactee cult groups. Others are set up as study groups or around a project, such as the saucer-building group mentioned above. These groups borrow skills and ideas from nontraditional religious systems (such as theosophy) as well as from psychic societies; they also draw upon UFOlogy, though to a lesser extent than one might expect. The members of these groups are largely working class or lower middle class and tend to have a lower educational level than UFOlogists, to whom we will next turn our attention. The religious needs to which these groups appeal and the opportunity for sociation in the doctrinally tolerant context they provide will probably make the contactee subculture viable for many years to come.

Collective Behavior or Protoscience?

UFO sightings, and those who investigate them, can be viewed in either of two very different ways. On one hand, the phenomenon might be seen as an example of collective behavior and the contagion of perceptual experiences, and one might seek the supposed "structural strains" that led to the outbreak of such experiences in American society. Or it might be seen as the courageous struggle of inquisitive amateurs to bring to light events that the scientific community would just as soon ignore. Both views have some substance, and both can be supported by emphasis on one or another portion of the social behavior exhibited by sighters, investigators, the mass media, the military, and the scientific community (to name only a few of the actors involved). The treatment of UFO experiences by American society is complex, and here we can only sketch its outlines.

While experiences that might be labeled "UFO" go far back in history, the concept "flying saucer" was first applied to an actual experience in June 1947, after a spectacular sighting near Mount Rainier led to extensive newspaper coverage. Within weeks, hundreds of sightings had been reported in newspapers all over the United States. One sociologist, Herbert Blackett, was convinced that the flying saucer "craze" was "almost wholly a manufactured concept" and that it would quickly disappear. This expectation, however, was incorrect. The vividness and popularity of the "flying saucer" (a.k.a. "unidentified flying object") concept meant that it could and would be applied to a large number of aerial objects—some of them, to be sure, identifiable enough. In the 1960s, public opinion polls showed that about one in twenty adults felt that he/she had seen a UFO; by the 1970s, this figure had risen to one in ten. Not only did UFO sightings not go away, they continued in full force, although their apparent extent has varied with shifting media coverage.

Interestingly enough, UFO sighters are roughly a cross section of the American population. They are not distinguished from nonsighters by income, education, race, sex, or religion. Although one study did suggest that some of them might be status-inconsistents, a follow-up study did not support this hypothesis. There is, however, one factor that is consistently related to UFO sightings, and that is youthfulness. The data show that the younger one is, the more likely one will report having sighted a UFO. While the meaning of this finding is not clear (it may have to do with differential willingness to label a perception a "UFO"), it suggests that there is some re-

lationship between social structure and UFO observations. That there is, also, a strong predisposition for people to perceive UFOs, as indicated by the ability of UFOlogists to identify about 90 percent of reported sightings as known objects. UFOs, then, are part of our culture—and of the cultures of other nations, as well, since UFO sightings are a worldwide phenomenon.

The intense interest that UFO sightings evoke, of course, has to do with the possibility that some of the observed objects might be extraterrestrial vehicles. This possibility, and others, led to the early investigation of sightings by the American armed services, notably the U.S. Air Force. In the twenty-year period that the Air Force was publicly involved in the investigation of UFO sightings, it would sponsor two major studies—one by the Battelle Memorial Institute, the other by the University of Colorado. The overall conclusion of both studies was that UFOs did not provide evidence of extraterrestrial visitation, although the data were actually far from unequivocal. In both cases, there is some evidence of analysis being slanted to please the sponsors of the research. The Air Force's own UFO investigation unit, variously called Sign, Grudge, and Bluebook (reflecting its shifting orientation), was under even more pressure to come up with negative conclusions, and usually did.

Continuing publicity given to UFO sightings by the mass media, magazines, and books made some of the public impatient with Air Force investigations, which seemed slow, uninspired, and perhaps dishonest. The latter impression was reinforced by the books of a retired Marine Corps major, Donald Keyhoe, who used contacts inside the Air Force to find out "what was really going on." The combination of curiosity and frustration led civilians to found their own organizations to investigate sightings. The Aerial Phenomena Research Organization (APRO) and Civilian Saucer Intelligence (CSI) were formed in 1952; and the organization destined to become the largest, the National Investigations Committee on Aerial Phenomenon (NICAP), was created by Keyhoe and others in 1956. At its peak, the now defunct NICAP had 10,000 members and published several large compilations of information on sightings. The largest and most active organization currently is the Mutual UFO Network (MUFON), which has about 1,500 members and an investigator network covering the United States. MUFON's annual conventions bring together many of the intellectual leaders of the UFO movement.

UFO-investigation organizations display many of the usual problems of voluntary associations. Success is often dependent on leadership; finances are a recurrent problem; ensuring membership participation and conformity requires strenuous effort; and factions are common. The organizations would like to present their work as scientific, but scientists are a tiny minority among UFOlogists. Typical of the problems faced is the constant struggle to get members to submit investigation reports on standardized forms, or to submit any reports at all. In spite of these difficulties, a fairly large volume of investigation (of varying quality) does get carried out, and many of the more interesting reports are published in UFO periodicals, conference reports, and books.

What is the nature of the knowledge so developed, and what is its value? This is very difficult to assess. Investigation of UFO sightings is carried out ordinarily as a hobby in one's spare time, on weekends, evenings, or on time bootlegged from one's job. The cost of investigating an interesting case probably approximates that of a difficult homicide investigation; the time and money for a thorough job are seldom available. The number of interesting cases of close encounters, landings, physical-trace cases, sightings of "humanoids," even "abductions" in the literature is quite large. It is as difficult for most insiders *not* to believe that something unusual is taking place as it is for outsiders to believe something is. Certainly the extent and strangeness of the reported events seem to call for continuing inquiry. Nor is it correct to believe that when scientific investigators look at the same cases, they find nothing. Both the Battelle Memorial Institute study and the University of Colorado study (popularly known as the Condon Report) had a large fraction of unexplained cases from "reliable witnesses."

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UFOs have not been entirely ignored by other scientists. In 1953, Donald Menzel, a distinguished astrophysicist at Harvard, published *Flying Saucers*, a substantial book whose thesis was that sightings are largely attributable to aerial mirages. Although his specific optical explanations were later discounted, Menzel's authority was probably quite influential in persuading his colleagues not to take UFOs too seriously. (Menzel's coauthored second and third books appeared in 1963 and 1977.) In 1965, a different approach was taken by the astrophysicist and computer scientist Jacques Vallee, whose *Anatomy of a Phenomenon* turned Menzel on his head. Menzel had argued that people were good at seeing what was not there; Vallee argued that society was good at not seeing what was there, and that the UFO reports and science's response to them were well within the parameters for a real extraterrestrial visitation. Vallee's thesis received additional support in 1972 with the publication of J. Allen Hynek's *UFO Experience*.

Hynek's book was the first truly scientific examination of the UFO phenomenon. At the time, Hynek was chairman of the Department of Astronomy at Northwest-

ern University, and he had served for many years as the major Air Force consultant on UFOs, a position that won him little sympathy from UFO advocates. His "swamp gas" explanation of the 1966 Michigan sightings had become a national joke. Yet, his book was remarkable in two respects. First, unlike the books of Menzel and Vallee, it was based almost entirely on his own field research. The others had relied largely on secondary accounts—some of which were later shown to be fraudulent—and theoretical arguments. Second, it suggested a classification of UFO phenomena that is still widely used by UFO investigators and enthusiasts and that permitted a specialization which characterizes much contemporary UFO investigation. Hynek's books were eventually followed by other scientifically oriented works, and his Center for UFO Studies in Evanston, Illinois, carried out investigations leading to Allen Hendry's *UFO Handbook*, a comprehensive analysis of 1,307 UFO cases, of which 9 percent remained unidentified after investigation.

Doubters of the reality of UFO sightings have also been active, principally in the person of Philip J. Klass, a senior editor of *Aviation Week*, whose book (in 1968) suggested that UFO sightings were attributable to ball lightning. His next books, in 1974 and 1983, concentrated more on the possibilities of optical illusion and fraud. Energetic, inquisitive, and somewhat ruthless, Klass came to provide a constant counterpoint to proponents' claims that this or that sighting was unexplainable. He was joined by James Oberg and Robert Sheaffer, both of whom later wrote their own debunking books on UFOs. Oberg, like Klass, is a science writer; Sheaffer is an engineer. All three are members of the Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP), an organization set up to debunk paranormal beliefs. The critics focus on the weak points in the proponents' arguments, reinvestigate in some cases, and criticize them in the mass media. In recent years, there have been many heated exchanges between proponents and critics, in print and in person, but with little resolution of basic differences.

The UFO investigation community, then, consists of a large number of interested amateurs, a small number of scientists, and a handful of active critics. This community has developed its own literature, its own folkways, its own jargon, and its own knowledge base. Not all UFOlogists feel that the evidence points to extraterrestrial visitation. But most believe that something very much out of the ordinary is taking place. One day, perhaps, UFOlogy will be placed alongside phrenology as a deviant and unsuccessful paradigm. Its practitioners, however, see themselves as pioneers in the recognition of the first manifestations of a nonhuman intelligence.

Is Anyone Out There Sending?

While UFOlogists are looking for extraterrestrials in the atmosphere, another group is seeking evidence in the form of electromagnetic signals from distant stars. Members of this group, the SETI (search for extraterrestrial intelligence) community, are almost all scientists who tend to think that telepathy or flying saucers are irrelevant to ETI contacts. If such contacts are to be made, some form of electromagnetic energy—radio, light, etc.—is the likely channel. This group's attention, theoretical effort, and attempts to obtain funding thus center around the means for detecting such signals. The members of the SETI community (most visibly represented by astronomer Carl Sagan) are largely astronomers, engineers, astrophysicists, and biologists who share a common framework for discourse, although they often differ on the "realistic" estimates for the quantities which interest them. The majority, however, think that intelligent life elsewhere in the universe is very probable, if not certain.

While the notion of intelligent life on other worlds goes back to ancient times, the SETI movement is barely a quarter of a century old. Its beginning might be traced to a 1959 article, published by physicists Giuseppi Cocconi and Philip Morrison in the respected British journal *Nature*, that attracted wide attention. The next year, Cornell astronomer Frank Drake conducted OZMA, the first search for extraterrestrial radio signals. And in 1961, at a meeting convened by the National Academy of Sciences at Green Bank, West Virginia, the movement crystallized. During that meeting, one of the eleven participants, Melvin Calvin of Berkeley, was notified that he had won a Nobel Prize; this incident is indicative of the status of many members of the SETI community. Most are PhDs at leading universities or prestigious research institutions. Four members of the Green Bank group have continued to work on SETI: Morrison at MIT, Drake at Cornell, Carl Sagan (also at Cornell), and engineer Bernard Oliver, who is vice-president for research at Hewlett-Packard. Another central figure in SETI research is the British physician John Billingham, now chief of the Extraterrestrial Research Division at NASA's Ames Research Center in California.

Since this group has strongly influenced intellectual discussion and research efforts, its basic assumptions are worth considering:

- First, the development of life is a natural process—merely a matter of probability, not a miracle requiring divine intervention. Thus, given the enormous number of stars likely to possess planets, the chances are extremely high that life has originated not once, but many times.
- Second, the development of intelligent life is also a matter of probability and is also to be regarded as a natural process. There are differences regarding how intelligent life is likely to develop and how closely it is likely to resemble Homo sapiens. George Gaylord Simpson, an authority on evolution, considers the chance of anything resembling man in intellectual capacity to be vanishingly small. Others, such as Carl Sagan and Frank Drake, are much more optimistic.
- Third, these civilizations are likely to carry on com-

munications with the planets of other stars not by means of spacecraft but, rather, through the medium of electromagnetic signals. The distances between inhabited planets are simply too great to make interstellar travel common or even feasible.

- Finally, since the distances are so great, the time required even for radio signals must make two-way communication a very long process. It would take eight years for a single message and reply between earth and the nearest star system. Thus, it is simpler and cheaper to begin by trying to detect others' signals. If these attempts succeed, then we can consider sending replies. To send messages, now, however, without knowing where to send them, would be a waste of scarce resources. Thus contemporary American efforts focus on SETI, searching for ETI, rather than CETI, communicating with ETI.

There have been twenty-two searches for such signals, none successful. This lack of success is not surprising. The searches have sampled only an infinitesimal fraction of the sky and have used only a very narrow range of radio frequencies. As assumptions about what to look for and where to look change, and as the technology of search instruments steadily improves, there are likely to be many more searches.

SETI faces three obstacles: funds, competition for search frequencies with other users, and opposition within the scientific community. Funds are a serious problem for SETI. All the searches thus far have been conducted with small budgets and rather primitive data-processing equipment, and they have been able to cover only a small portion of the sky. One 1971 design, Project Cyclops, called for a system that would have cost perhaps $20 billion, but funding at this level is unthinkable. The current, far more modest system, which concentrates on signal processing rather than on reception capabilities, was designed to require a startup cost of $2 million for 1982. Initially, Congress turned the request down, but in 1982 it did budget $1.5 million for 1983. These funds were to cover only the first five years of R&D on a multichannel spectrum analyser, to be conducted by Stanford University in cooperation with the Jet Propulsion Laboratory. The system will be able to process 74,000 channels simultaneously, once developed. Five years will be spent on the actual search.

Another problem is that the frequencies desired by SETI investigators are also being sought for more mundane uses. For instance, the 1400-to-1727-megahertz band—thought to be an obvious "window" for interstellar communication—is also used for mobile communications, satellites, and radiosondes on weather balloons. While SETI investigators want these frequencies to be kept open for ETI searches, other interest groups have their own agendas. Furthermore, use of the radio spectrum is an international matter, and agreements have to be negotiated through the World Administrative Radio Conference, which includes 150 nations.

Still another problem is that more than one view exists in the SETI community. A strong minority position, first articulated by Michael Hart of Trinity College, Texas, holds that humans may well be the only intelligent life in the universe. Hart's view also differs from the majority in that he thinks space travel is not only a possibility, but a certainty, with technically advanced civilizations. If there were ETI, its presence would be manifest on earth; since there are no ETIs on earth there is no ETI. Other "pessimists," less willing to concede the feasibility of space travel, take issue with other tenets of the majority view, such as the likelihood of other planets that support life. The creation of intelligent life on earth required, it is suggested, so many "lucky accidents" that one can regard it almost as a miracle. These and similar concerns were instrumental in bringing the minority together for the first "we are all alone" conference in 1979. While this minority is still small, its influence and power are growing. Once the majority view was so strong that it was difficult for the pessimists even to publish papers in the more established journals. Now this trend is gradually being reversed.

Although their work and thinking have been highly publicized, the number of scientists directly involved with SETI is quite small. Few, if any, scientists devote all their time to it. Probably fewer than a dozen give most of their energies to projects specifically dedicted to SETI work; probably fewer than a hundred scientists are working in areas closely related to SETI. Although a majority of Americans believe that there is intelligent life elsewhere in the universe, they have devoted relatively few resources to searching for it.

Whereas Donald Menzel had argued that people were good at seeing what was not there, Jacques Vallee argued that society was good at not seeing what *was* there.

Two factors account for this limited activity. First, many of the researchers active in SETI are also busy in other, more conventional research activities. Since the chances that any one individual will make a major discovery in SETI appear so slight at this time, the ambitious scientist is reluctant to divert much energy away from other activities having a higher probability of success. Second, it is very difficult to get funding for SETI research. Contrary to a prevalent misconception, SETI funding from the National Science Foundation and NASA has ranged from nonexistent to nominal. Even in its more prosperous years, the SETI unit in NASA had only one or two scientists and a small secretarial staff.

Thus, although well trained and influential, the active

SETI community is relatively small. Though its funding is modest, its prestige and access to the instrumentation and talent of neighboring specialties have allowed it both to carry out research and to publicize its activities. The impact of this group on our society testifies to its intellectual power.

Signals and Noise

In a 1977 report prepared for the U.S. House Committee on Science and Technology on the subject of ETI, one can find this interesting sentence: "Many supporters of the thesis that there are other intelligent civilizations do not support the contention that they have visited Earth—UFOs are not discussed in this report." This remark, which expresses widespread and quite strong sentiments in the SETI community, points to a striking division between UFOlogy and SETI, two human enterprises that otherwise might be seen as closely connected. Both, after all, presume highly advanced extraterrestrial civilizations as well as efforts by those civilizations to communicate with others. Obviously, such civilizations might choose more than one means of exploration or communication, and it would seem difficult a priori to determine the most likely means. Both subcultures have the problems of separating "signal" and "noise" in regard to data. Yet the prestige of these two fields of endeavor could hardly be more different, nor their participants more strongly opposed to each other's views. For all intents and purposes, these two research efforts might as well be taking place in different countries, since they appear so far apart intellectually.

This gap between the two subcultures shows up in several ways. Most conspicuous is the lack of citation of each other's work in publications. Although the work of the two groups would seem complementary—after all, they are exploring different aspects of the same problem—such complementarity is not acknowledged by either side. Similarly, those who attend the meetings, conventions, and briefings of one subculture seldom appear at those of the other. Finally, there are occasions when one subculture publicly attacks the other. One instance was a program in the *Cosmos* television series, narrated by Carl Sagan. In the program, Sagan's treatment of UFOlogy was largely negative; and since the series received enormous popular attention, it is to be presumed that his views were quite influential. Similarly a *Nova* program on UFOs was co-opted by the UFO critics, whose views were not only more frequently quoted, but were also given more sympathetic treatment. It might be that the tendency of the news media to find an "angle" for a given program makes them tilt more toward one side or the other, rather than present a balanced approach.

But there are rare occasions when the gap is bridged. Carl Sagan and Frank Drake were responsible for a panel on UFOs at the 1969 meetings of the American Association for the Advancement of Science. The participants included proponents, critics, and neutrals; the selection of speakers and topics was remarkably evenhanded. Sagan had also participated in the 1968 hearings before the House Committee on Science and Astronautics which dealt with UFOs, even though most of the speakers presented pro-UFO statements. Yet, despite these contacts, neither subculture appears to have had any real impact on the other. We are left, then, with a need to explain this phenomenon.

The first major cause of the separation lies in the histories of the two subcultures. UFOlogy was begun by amateurs and remains largely an amateur pursuit; this is reflected in its conferences and publications, and in the quality of the typical UFO investigation. The scientists and engineers who participate in UFOlogy have been for the most part recruited by the amateurs, and often have joined them only reluctantly. UFOlogy, furthermore, has a lunatic fringe from which it has been unable to disassociate itself. Although some UFO organizations, like NICAP, have tried to develop strict rules for what will be admitted as genuine UFO cases, the ambiguity of the data has not permitted these boundaries to be shared universally among influential UFOlogists. If one cannot definitively determine what is a UFO and what is not, cloture is very difficult. One might call UFOlogy an "incomplete paradigm." Furthermore, the realities of the lecture circuit and the media have often tempted "serious" UFOlogists to share the spotlight or the rostrum with other groups whose views they do not completely accept. The net result is that there is no well-demarcated "amateur" subculture that can be co-opted by the broad scientific community, let alone by SETI.

"UFOlogy" has a lunatic fringe from which it has not been able to disassociate itself.

The SETI community, on the other hand, began and remains an "invisible college" within the scientific community, and the chosen technology—electromagnetic receivers—simply does not permit amateur participation. Many of its members are scientists of considerable prestige, and even those who disagree with the majority position accept the conventions and folkways of the scientific community. The intellectual weight that can be brought to bear in favor of SETI is truly impressive. In 1982, Carl Sagan organized a petition with sixty-eight other signatories in favor of an international SETI project. The list reads like a "Who's Who" in astronomy, physics, and biology. Seven Nobel prize-winners are included. Thus, unlike the UFOlogists, whose social situation often dictates uneasy alliances, the

SETI investigators have no need for compromising ties. There is, however, one tie of dependence which is important, and that is to the organs of funding. The legitimacy and the funding of SETI research is tied to its position within the scientific community, and to the prestige of its members.

This leads us to the second major reason for the gap. Not only is UFOlogy a potential contender for government funds, but any association between UFOlogy and SETI would have negative implications for SETI funding. The potential threat of such an association is that the ridicule often attaching to UFOlogy might spread to SETI research. Given the current congressional attitude that SETI research is questionable anyway, an association with UFOlogy might burden it with an unshakeable albatross. (Conversely, it would provide UFOlogy with some very prestigious defenders.)

> The ways in which humans have responded to the concept of extraterrestrial intelligence reveal a good deal about who *we* are.

One incident nicely illustrates the dangers to SETI of UFOlogical involvement. One participant in the 1971 debate over the supersonic transport (SST) before the U.S. House of Representatives was the distinguished meteorologist James McDonald. When McDonald gave testimony as to what he believed the effect of the SST on the atmosphere would be, his views on UFOs were brought up in order to ridicule him and discredit his testimony. He was actually laughed at during the hearing. One congressman suggested that "a man who comes here and tells me that the SST flying in the stratosphere is going to cause thousands of skin cancers has to back up this theory that there are little men flying around in the sky. I think this is very important." It does not require much imagination to anticipate how a similar association between SETI and UFOs might affect the funding chances of the former. After criticism of the current SETI microwave program appeared in *Science* magazine, one of the program's originator's felt it necessary to assert that SETI "is now, and has been for decades, a scientific endeavor." Hence, whatever the private views of SETI investigators about UFOs, it is in their interest to maintain a complete dissociation in public. Since even the UFOlogist's existence is seldom acknowledged by SETI investigators, the UFOlogists, too, have reason for maintaining the separation. Why should they try to approach those who so strongly reject them?

The gap between the two subcultures, then, ostensibly an intellectual question ("the UFO evidence is just too weak"), is exacerbated by a conflict of intellectual styles and a struggle for legitimacy and funding. It is evident that some of the intellectual bases for disagreement ("the stars are too far away") between SETI investigators and UFOlogists are questioned even by some of the former (for instance, Michael Hart). Both, furthermore, can always come up with new projects: a single ETI signal or a single proved UFO case would instantly propel either activity into priority status, but to prove that there are *no* UFOs or ETIs is difficult, if not impossible. It is not impossible, then, that the two subcultures will continue to work in virtual isolation from each other.

We have seen in these three subcultures three distinct responses to the concept of extraterrestrial intelligence. In each case, the talent, resources, and folkways of the subculture have contributed to shaping intellectual orientations and activities. Just as it seems perfectly logical in the contactee subculture to search for quasi-religious messages from "space brothers," it seems logical to UFOlogists to interview witnesses of strange aerial objects, and logical to SETI investigators to look for electromagnetic signals from distant planetary systems. Each of these responses shows a human attempt to reach out, to understand, and to grapple with the possibility that we are not alone in the universe. Each betrays the hopes, fears, beliefs, and abilities of the people involved. In contemplating the consequences of actual contact, it might be well to try to understand the inner spirit of each of these endeavors, since they reveal a good deal about who *we* are.□

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Ron Westrum is professor of sociology at Eastern Michigan University, where he is associate director of the Center for Scientific Anomalies Research. He is the principal author of Complex Organizations: Growth, Struggle, and Change, *forthcoming from Prentice-Hall.*

David Stupple, who died last year, was associate professor of sociology at Eastern Michigan University. Interested in all forms of popular culture, he specialized in the study of flying saucer groups and traditions.

David Swift is professor of sociology at the University of Hawaii–Manoa and contributing editor of Astrosearch. *His reports on space-related issues have appeared in* Astronomy, Omni, Astronautics *and* Aeronautics, *and other U.S. publications.*

II. SPACE LAW

COMMERCIAL SPACE ACTIVITIES UNDER THE MOON TREATY*

Martin Menter**

I. INTRODUCTION

The Moon Treaty, on adoption, will establish the principle that the moon and its natural resources are the common heritage of mankind. The establishment of an international regime is contemplated to govern exploitation of such resources with "equitable sharing" by all States in the benefits derived from those resources, with "special consideration" for developing countries and countries contributing to the exploitation. This paper examines the apprehension of private enterprise to invest funds in a moon activity requiring sharing of profits with States that had not shared in the risks involved. In light of the Treaty's negotiated history, conclusions made are that the nature of the sharing has not yet been determined; that such must await a subsequent separate treaty negotiation for the governing international regime when exploitation "is about to become feasible," an eventuality perhaps thirty or more years from now; that in the interim, there is no moratorium on exploitation and States may authorize their governmental and nongovernmental entities to undertake exploitation of the moon's resources. Private sector planning for and investment in commercial space activities, with Government support, is encouraged.

II. INTERNATIONAL COOPERATION IN SPACE ACTIVITIES

A. The Space Law Treaties

The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (TOM), on December 5, 1979, was recommended by resolution of the United Nations General

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** Vice-President, International Institute of Space Law, IAF; Past President (1977-1981), Association of United States Members of the International Institute of Space Law, IAF; Member, International Academy of Astronautics; Member AIAA Copyright © 1980, Martin Menter.

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Assembly for signature and ratification.[1] Like its three predecessor treaties formulated by the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) since adoption in 1967 of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies[2] (OST), the TOM is an expansion of principles embraced in the basic OST governing space activity. The TOM carries forward the OST objectives of international cooperation in space activities, with all nations to share in the benefits of space exploration without regard to their level of economic or scientific development.[3]

B. Freedom from Sovereignty

The appeal of the OST for international accord in exploration and use by all States was strengthened by the omission of the historical concept applicable to discovery and exploration of land masses on Earth, viz: the obtaining of sovereignty upon "effective occupation" over a *terra nullius*. In lieu thereof, the OST proclaimed, "Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use, or occupation or by any other means."[4] Without this provision, States which established settlements on celestial bodies or otherwise in space might well be reluctant to then surrender

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1. G.A. RES. 34/68, 34 U.N. GAOR, Supp. (No. 46) 77, U.N. DOC. A/Res/34/68 (1979) [generally known as the "Moon Treaty," hereinafter cited as the TOM]. The text of the Treaty is contained in the Annex.

2. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, *done* Jan. 27, 1967, 18 U.S.T. 2410, T.I.A.S. No. 6347, 610 U.N.T.S. 205 (*effective* Oct. 10, 1967) [popularly known as the "1967 Treaty on Outer Space," hereinafter cited as OST]. The three interim predecessor treaties were: Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, *done* Apr. 22, 1968, 19 U.S.T. 7570, T.I.A.S. No. 6599, 672 U.N.T.S. 119 (*effective* Dec. 5, 1968); Convention on International Liability for Damage Caused by Space Objects, *done* March 29, 1972, 24 U.S.T. 2389, T.I.A.S. No. 7762 (*effective* Oct. 9, 1973); Convention on Registration of Objects Launched into Outer Space, *done* Jan. 14, 1975, 28 U.S.T. 695, T.I.A.S. No. 8480, (*effective* Sept. 15, 1976).

3. See OST, *supra* note 2, at Preamble, art. I; TOM, *supra* note 1, at Preamble, arts. 2, 4.

4. OST, note 2 *supra*, at art. II. For a discussion of application of prior principles to space discovery and settlement in the absence of an international accord precluding vesting of sovereignty, *see* M. Menter, Jurisdiction Over Land Masses in Space, address at the American Rocket Society Space Law and Sociology Conference, Carnegie Endowment for International Peace Building, New York City (Apr. 24, 1962).

whatever inchoate sovereignty rights accrued by such settlements. Many an armed conflict emanated from conflicting sovereignty claims on Earth; this possibility in space was to be avoided. The time to resolve this foreseeable problem was before such space exploration and settlement could occur.

The TOM contains a similar recital against national appropriation of the moon.[5] While some writers and States had contended that the OST Article II prohibition would preclude exploitation of the moon's natural resources, the prevailing view appears to permit such exploitation.[6] It is believed that the intent of this provision was to preclude application of the historical concept of sovereignty attaching to exploration and establishment of dominion over newly discovered portions of the Earth.

III. THE PRIVATE SECTOR IN SPACE

A. Space Communications

Private sector commercial space activities by U. S. companies followed the enactment by the U. S. Congress of the Communication Satellite Act of 1962.[7] The act established the Communications Satellite Corporation (COMSAT) which was authorized to create and operate, or in conjunction with foreign governments or business entities to operate "a commercial communications satellite system."[8]

B. Remote Sensing

Private sector ownership and management of a civil operational land remote sensing activity is currently being studied by the U. S. Government. Planning and development responsibilities therefor were assigned by the President on November 20, 1979 to the National Oceanic and Atmospheric Administration (NOAA) of the U. S. Department of Commerce.[9] On June 20, 1980, the NOAA issued a document setting forth issues and options being con-

5. TOM, *supra* note 1, at art. 11, para. 2.

6. 1 MANUAL OF SPACE LAW 264 (N. Jasentuliyana, R. Lee eds. 1979).

7. 47 U.S.C. § 701 (1976).

8. *Id.* at § 731.

9. The Nov. 20, 1979 presidential directive was premised upon an Interagency Task Force study "Private Sector Involvement in Civil Remote Sensing," dated June 15, 1979. The Nov. 20, 1979 White House Release is reprinted as "Attachment A" to the NOAA June 20, 1980 Doc. "Planning for a Civil Operational and Remote Sensing System: A Discussion of Issues and Options."

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sidered by the Federal Administration in the development of its 1982 fiscal year budget and legislative program.[10]

C. *Congressional and Executive Interest in Future Spoce Endeavors*

In the U. S. Congress 96th session, both houses of Congress have held hearings in good part to ascertain and encourage private sector involvement in space activities[11] and to evaluate the current U. S. Civil Space Policy. The Policy, announced by the President on October 11, 1978, increased participation by the private sector in space enterprises. Among other recitals, the announcement stated that the Policy was to "confirm our support of the continued development of a legal regime in space that would assure its safe and peaceful use for the benefit of mankind."[12]

There is no doubt that the Administration and the Congress desire to assure that the private sector, under Government aegis, will share in such space endeavors as envisaged by the concise apropos remarks of Ambassador Peter Jankowitsch, Chairman of the UN COPUOS,[13] at the opening of the Committee's 1979 session:

> We are now seriously considering daily flights to orbit which might serve and supply large technical facilities such as research laboratories, astronomical laboratories, earth resources observatories, manufacturing facilities or communication centres. We are also considering expanding direct-to-home television broadcasting through-out the world; and erecting large structures in space, stabilizing them and moving them about. The possible early demonstration of a large structure that could be part of a large

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10. *Id.* at 119. Legislative proposals under contemplation include a bill to establish the institutional framework and governmental financial assistance for eventual private sector ownership and operation of a civil operational land remote sensing system.

11. *See* The National Space and Aeronautical Policy Act of 1979, S. 212, 96th Cong., 1st Sess. (1979); Space Flight Policy Act of 1979, S. 244, 96th Cong., 1st Sess. (1979); Earth Resources Information Corporation Act of 1979, S. 875, 96th Cong., 1st Sess. (1979); Space Industrialization Act of 1980, H.R. 7412, 96th Cong., 2d Sess. (1980).

12. White House Fact Sheet of Oct. 11, 1978, *reprinted in* SENATE COMM. ON COMMERCE, SCIENCE AND TRANSPORTATION, 95TH CONG., 2D SESS., SPACE LAW-SELECTED BASIC DOCUMENTS (2d ed.) 561 (1978). A White House Press Release of June 20, 1978 announced the Committee's establishment within the Executive Office of the President with the objective among others, of "[the encouragement of] domestic commercial exploitation of space capabilities and systems for economic benefit . . .". *Id.* at 559.

13. United Nations Committee on the Peaceful Uses of Outer Space [hereinafter cited as COPUOS].

solar experiment is under active consideration. And finally, we are examining the possibility of setting up larger, earth-like communities several hundred thousand miles up in space.[14]

D. Activities in the Moon and other Celestial Bodies

The TOM expressly recognizes that the private sector may engage in activities on the moon. In language patterned after Article VI of the OST, the TOM states that "non-governmental entities" under the jurisdiction of a State Party to the Treaty may engage in national activities on the moon. However, such activities are to be "only under the authority and continuing supervision of the appropriate State Party."[15]

It should be noted that by reason of express recitals in the initial article of the TOM, its provisions relating to the moon are also applicable to other celestial bodies other than the Earth, including "orbits around or other trajectories to or around" the moon.[16] However, such orbits and trajectories "do not include trajectories and orbits of space objects in earth orbit only and trajectories of space objects between the earth and such orbits."[17] In this paper, all references to the moon shall likewise be deemed to be applicable to other celestial bodies, unless it is otherwise apparent from the context.

IV. EXPLOITATION OF MOON RESOURCES

A. The Common Heritage Principle

The provisions of the TOM of most significance to commercial operations under the Treaty concern the exploitation of the natural

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14. Report of COPUOS, 34 U.N. GAOR, Supp. (No. 20) 30, U.N. Doc. A/34/20 (1979).

15. TOM, *supra* note 1, at art. 14, para. 1. The wording of the prior Art. VI, OST was taken from para. 5 of 18 U.N. GAOR, Supp. (No. 15) 15, U.N. Doc. A/5515 (1964). Declaration of Legal Principles Governing Activities of States in the Exploration and Use of Outer Space. The wording was that proffered by the U.S.S.R. except for substitution on the suggestion of the U.S. Delegate of the term "non-governmental entities" for "non-governmental bodies corporate" 18 U.N. GAOR ____, ____, U.N. Doc. A/AC.105/PV.24 (1963). In a discussion leading to the formulation of this principle, the Soviet Delegate remarked:

> The Soviet delegation considers it essential to point out that in this field it would be possible to consider the question of not excluding from the declaration possibility of activity in outer space by private companies, on the condition that such activity would be subject to the control of the appropriate State and the State would bear international responsibility for it.

16. *Id.* at art. 1, para. 2.

17. *Id.* at Preamble; Report of the COPUOS, *supra* note 13, at 11, para. 63.

resources of the moon. It was after a stalemate of seven years that a compromise permitted the attainment of a consensus on the present draft. This compromise is contained in Article 11, which states in its initial paragraph: "The moon and its natural resources are the common heritage of mankind, *which finds its expression in the provisions of this Agreement, in particular in paragraph 5 of this article*."[18] (emphasis added). The compromise provision was the addition of the emphasized wording purporting to limit the derivation or meaning of "common heritage of mankind" to the TOM, rather than to the use of such phrase elsewhere.

A brief review of the development of the common heritage of mankind concept (hereinafter referred to as the "CHM") in the TOM may be helpful. The 1971 UN General Assembly session requested COPUOS and its Legal Subcommittee to consider, as a priority matter, the question of the elaboration of a draft treaty concerning the moon.[19] In its request, the Resolution took note of "A Draft Treaty Concerning the Moon" submitted by the USSR to the UN General Assembly's First Committee.[20] This draft, however, was devoid of the CHM. Such concept had previously been proposed by Argentina during the 1970 COPUOS Legal Subcommittee Session in a proposal concerned only with the use of the natural resources of the moon and other celestial bodies.[21] The concept was adopted by the United States in the draft proposal it submitted in April 1972[22] at the COPUOS Legal Subcommittee Session which was considering the desirability of a TOM pursuant to the request of the UN General Assembly. The CHM was concisely stated in the U. S. draft as "The natural resources of the Moon and other celestial bodies shall be the common heritage of all mankind."[23]

It would appear that the U.S., at the time of the submittal of the CHM had in mind the similar recital in the proposed Law of the Sea (LOS) seabed treaty. On May 3, 1972, the U.S. Representative to the Legal Subcommittee in a statement concerning the natural resources of the moon and other celestial bodies stated: "This [CHM] would parallel policy proposed by President Nixon

18. TOM, *supra* note 1, at art. 11, para. 1.
19. G.A. RES. 2779, 26 U.N. GAOR, Supp. (No. 29) 28, U.N. DOC. A/8429 (1972).
20. U.N. DOC. A/C.1/L/ 568. (?)
21. U.N. DOC. A/AC.105/C.2/L.71 and Corr. 1. (?)
22. U.N. DOC. A/AC.105/C.2(XI)WP12 Rev. 1 (1972).
23. *Id.* at para. 1.

two years ago . . . that all nations should regard the resources of the seabed . . . as the common heritage of mankind."[24]

The U.S. introduction of the CHM met with mixed reception. The USSR opposed the CHM[25] until it accepted as as a compromise the more limiting revised Article 11 which contained the additional circumscription to the CHM: "which finds its expression in the provisions of this agreement, in particular in paragraph 5 of this article."[26] Paragraph 5 provides:

> States Parties to this Agreement hereby undertake to establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible. This provision shall be implemented in accordance with Article 18 of this Agreement.[27]

B. The International Regime

The international regime's main purposes as recited in Article 11, paragraph 7, are the orderly, safe development and rational

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24. Statement by U.S. Representative Herbert Reis, contained in U.S. Mission release, Geneva, Switzerland, May 3, 1972, p.6. In an exchange of views, with the U.S.S.R. during the following year session of the Legal Subcommittee as to the legal substance of the CHM, the Argentine delegate observed that the UN General Assembly Resolution 2749 25 U.N. GAOR, Supp. (No. 28) 24, U.N. Doc. A/8028 (1971) adopted without dissenting vote, was "proof of the existence of this legal viewpoint common to all States, irrespective of their special internal features, their philosophical ideas or their policies" ___ U.N. GAOR, ___, 29-31, U.N. Doc. A/AC.105/115 (1973). The referenced Resolution in part declared: "1. The seabed and ocean floor, and the subsoil thereof, beyond the limits of national jurisdiction . . . as well as [its] resources . . . are the common heritage of mankind." 25 U.N. GAOR, Supp. (No. 28) 24, U.N. Doc. A/8028 (1971).

25. *See* U.S.S.R. Working Paper, 28 U.N. GAOR ___, ___, U.N. Doc. A/AC.105/101, para. 21 (1973) *reprinted in* 1977 COPUOS Legal Subcommittee Report, 32 U.N. GAOR ___, ___, U.N. Doc. A/AC.105/196, Annex I, 11-12 (1977). The U.S.S.R. favored substitution of the prior used and understood phraseology "common province of all mankind," observing that under the OST celestial bodies "are available for the undivided and common use of all States, but not jointly owned by them. This is the essential feature of international law."

In 1976, Ambassador Piradov of the U.S.S.R., at the COPUOS, observed: "First, we are genuinely convinced that such a proposal is premature in the absence of the necessary objective foundations and factual material for it. Secondly, we have referred to the juridical and political vagueness and lack of specificity in the concept which has been put forward." 31 U.N. GAOR ___, ___, U.N. Doc. A/AC.105/PV 158, 8-10 (1976).

26. TOM, *supra* note 1, at art. 11, para. 1.

27. Art. 18 provides that the question of whether exploration is about to become feasible will be an agenda item of the UN General Assembly ten years after the TOM has come into force; further such question may also be considered by a review committee after the TOM has been in effect for five years, upon the request of one-third of the States Parties to the TOM with the concurrence of a majority of the States Parties. TOM, *supra* note 1, art. 18.

management of the moon's natural resources, the expansion of opportunities for the use of such resources, and an "equitable sharing" in the "benefits derived from the resources" by all States Parties, with "special consideration" being given to the efforts of those countries which have contributed either directly or indirectly to the exploration of the moon as well as to "the interests and needs of the developing countries."[28]

1. PRIVATE SECTOR CONSIDERATION

Intrinsic to the consideration of the international regime are questions relating to authorization for exploitation of the moon's natural resources, the nature and limitations of the international regime, and when such regime and exploitation may come into effect. In the United States, serious consideration is being accorded to assertions that the CHM will lessen the incentive of the private sector to risk capital investment in space ventures involving exploitation of the moon's resources. The purpose of any commercial venture being financial gain, the indefiniteness of the CHM is said to render the possibility of such gain as too speculative and uncertain, including an unacceptable possible interpretation for sharing profits from risk capital investments with parties that did not share such risk.

It must be recognized that unlike the seabed whose resources are readily identifiable and obtainable, many years of effort—perhaps thirty or more—and unknown costs will be expended before exploitation of the moon can be determined as "about to become feasible."[29]

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28. TOM, *supra* note 1, art. 11, para. 7.

29. Charles Sheffield, President, American Astronautical Society and Vice-President, Earth Satellite Corporation, in recent testimony stated "these parameters may not be known well enough for another thirty or forty years to encourage a private investment group to operation on a for-profit basis in the field of off-earth mineral exploration." *The Moon Treaty, Hearings Before the Subcomm. on Science, Technology and Space of the Senate Comm. On Commerce, Science and Transportation*, 96th Cong., 2d Sess. 92 (1980) [hereinafter cited as *The Moon Treaty Hearings*]. Frosch, Robert, NASA Administrator, at the same Hearing testified that "[a]ny exploitation of extraterrestrial resources will require the development of new major technologies, . . . that planetary exploration will be required in order to fill the gaps in our knowledge of the nature and distribution of extraterrestrial materials." *Id.* at 37. He also observed that "a number of evolutionary steps of technology would be required to accomplish a demonstration of a Space Materials System." *Id.* at 38.

For an excellent presentation of lunar resources available, materials separation and processing to be undertaken, *see* testimony of Edward Bock, Project Engineer at Convair Div., General Dynamics Corp., and of Dr. James R. Arnold, Department of Chemistry, Univ.

2. THE MORATORIUM ISSUE

Other questions have been raised as to the nature and authority of the international regime envisaged by the TOM and whether a moratorium on exploitation of the moon's natural resources is required pending establishment and functioning of such regime. Further questions remain as to the possessory interest of a State or its nationals to the area of the moon occupied during exploitation of natural resources and to the resources removed.

C. Interpretation Problems

A reading of the TOM text, without consideration of its negotiated history, can be misleading. TOM contains key words that are undefined and which may infer an unintended meaning. In the COPUOS and its two subcommittees, agreement on a matter under consideration is obtained by consensus; that is, agreement is not obtained until no further objection is made. As objections are made, piecemeal changes are suggested. While the intent of a change would be clear at the time made, a reader of the entire provision not having the benefit of the detailed consideration accorded the total effort may readily arrive at a conclusion not in accord with the intent of the provision.

With forty-seven States represented at COPUOS and its subcommittee meetings, with each annual meeting able to allocate limited time for consideration of a given agenda item, with language difficulties sometimes occurring, and with the need to coordinate with home offices on changes of substance, the pressure for consensus on a General Assembly priority requested item may lead to reluctance to seek substantial revision when a recited interpretation appears to provide an acceptable resolution. With many cooks in the kitchen, we may question the appearance of slowly baked pie when removed from the oven; while digestibility

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of California at La Jolla. *Id.* at 147-64. *See also* Stanley Sadin, Dep. Dir., for Special Program Development at NASA's Office of Aeronautics and Space Technology, address at a Space Law Workshop, sponsored by the Association of United States Members of the International Institute of Space Law, at the Annual Meeting of the American Society of International Law, "The Moon Treaty: Should the United States Become A Party?" (Washington, D.C. 1980). After advising of the moon's resources and the method contemplated for their removal and transportation, Sadin observed that the most promising present utilization envisioned was in construction of a Solar Power System satellite space station. He cautioned, however, that this would first require many years of study and research.

may be difficult, it may nevertheless provide the needed sustenance.

1. The Vienna Convention on the Law of Treaties

In resolving questions raised as to the interpretation of provisions of a treaty or agreements incident thereto, Part III, Section 3 of the "Interpretation of Treaties" of the Vienna Convention on the Law of Treaties permits reference to UN documentation of the negotiated history and conclusion of the treaty, including agreements as to its interpretation.[30] It may be further noted that the "negotiated history" of a treaty includes "all manifestations of intention made during the course of negotiation . . . contained in the official records of the conference available to negotiators."[31]

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30. U.N. Doc. A/Conf. 39/27 *opened for signature*, May 23, 1969, *reprinted in* 8 Int'l Legal Mat'ls 679 (1969). The U.S. has not yet become a party to the Vienna Convention; however, its provisions here applicable reflect customary international law, and are as follows:

Article 31

General rule of interpretation

(1) A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose.

(2) The context for the purpose of the interpretation of a treaty shall comprise, in addition to the text, including its preamble and annexes:

(a) any agreement relating to the treaty which was made between all the parties in connexion with the conclusion of the treaty;

(b) any instrument which was made by one or more parties in connexion with the conclusion of the treaty and accepted by the other parties as an instrument related to the treaty.

(3) There shall be taken into account, together with the context:

(a) any subsequent agreement between the parties regarding the interpretation of the treaty or the application of its provisions;

(b) any subsequent practice in the application of the treaty which establishes the agreement of the parties regarding its interpretation;

(c) any relevant rules of international law applicable in the relations between the parties.

(4) A special meaning shall be given to a term if it is established that the parties so intended.

Article 32

Supplementary means of interpretation

Recourse may be had to supplementary means of interpretation, including the preparatory work of the treaty and the circumstances of its conclusion, in order to confirm the meaning resulting from the application of article 31, or to determine the meaning when the interpretation according to article 31:

(a) leaves the meaning ambiguous or obscure; or

(b) leads to a result which is manifestly absurd or unreasonable.

31. Restatement (Second) of Foreign Relations Law of the United States § 147 (1965).

2. Contending Interpretations

While the CHM, on introduction into the TOM, may have contemplated the concept as used in the LOS seabed treaty, it is clear that the revision accepted on the last day of the 1979 COPUOS session removed the LOS use as a binding interpretation and restricted the CHM meaning to the provisions of the TOM, particularly Article 11, paragraph 5. The question, however, remains as to what the latter may embrace. It will be recalled that in the referenced paragraph 5, the Parties "undertake to establish an international regime . . . to govern the exploitation of the natural resources of the Moon as such exploitation is about to become feasible."[32] Further, by paragraph 7(d), Article 11, the Parties to the TOM agreed to an "equitable sharing" in the benefits derived from such resources, as previously related herein.[33]

Views have been expressed by respected authors as to their belief of the meaning of the CHM as used in the TOM, ranging from application of the LOS purported use of CHM[34] (common ownership and profit sharing) to meaning the international cooperation that exists today in the equitable sharing of benefits of space applications with the international community.[35] Richard G. Darman, a lecturer in Public Policy and Management at the John F. Kennedy School of Government, Harvard University, in discussing Article 11 of the TOM, observed that the CHM "in and of itself, is but a vague phrase"; he noted that the international regime is similarly without specific definition, such essentially being left to future negotiations; and that neither the TOM nor the LOS seabed treaty negotiating text "refers to the other or to the other's specific domain."[36]

Ambassador Aldo A. Cocca, who, as the Representative of

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32. TOM, *supra* note 1, art. 11, para. 5.

33. *Id.* at art. 11, para. 7(d).

34. *The Moon Treaty Hearings*, *supra* note 29, at 105-132 (testimony of L. Ratinen).

35. U.N. General Assembly Press Release USUN—107 (79), Nov. 1, 1979 (statement by R.W. Petree to the U.N. General Assembly Special Political Committee in Consideration of the TOM draft) [hereinafter cited as Press Release].

Robert B. Owens, in testimony on the TOM, stated "our position in essence was that the common heritage concept . . . would simply parallel and conform to established space law, especially Articles I and II of the Outer Space Treaty . . . and that activities in such areas [of outer space] shall be for the benefit and interests of all countries." *The Moon Treaty Hearings*, *supra* note 29, at 13.

36. *The Moon Treaty Hearings*, *supra* note 29, at 168.

Argentina, first proposed the CHM at a COPUOS Legal Subcommittee Session in 1970, has recently written:

> As you know, it is rather dangerous to crystallize in a definition the principle involved in a concept which is just being born in the new domain of Space Law, such as the 'common heritage of all mankind,' as it was established in the Moon Agreement. As the 'international regime' is concerned, I dare say it is not a matter of definition; I feel it must be the outcome of the implementation of the guidelines set forth in the agreement.[37] Similar caution has been suggested by USSR[38] and US[39] COPUOS delegates.

V. THE NEED FOR LAW AND ORDER IN SPACE

A. Avoidance of Anarchy

The OST has assured that unlike discovery and exploration on Earth, a nation's sovereignty shall not attach to space, the moon or other celestial bodies by reason of space exploration or other action. With the advent of the Space Shuttle, we are at the threshold of a great expansion in space activities. "Anarchy in space could be more dangerous than anarchy on Earth," observed the late Justice Kenneth B. Keating.[40] It is plausible that international controls be sought for the common good of all States. While a "regime" conceivably can be but an agreed set of govern-

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37. Letter from Dr. Cocca to Mrs. Eilene Galloway, *reprinted in* SENATE COMM. ON COMMERCE, SCIENCE AND TRANSPORTATION, 96th CONG., 2D SESS., AGREEMENT GOVERNING THE ACTIVITIES OF STATES ON THE MOON AND OTHER CELESTIAL BODIES 58 (Comm. Print 1980).

38. Dr. Y.M. Kolossov, Alternate Head of the Soviet Delegation at the 1979 COPUOS session, on the last day of the session when the U.S.S.R. accepted the more limited CHM, observed: "Our delegation will make no hasty interpretation of the meaning behind each article of the new draft agreement . . . ." 34 U.N. GAOR ____, U.N. DOC. A/AC.105/PV.203, at 21 (1979).

39. S. Neil Hosenball, who chaired the U.S. delegation at the 1979 COPUOS session, in response to questions at a Congressional Hearing on September 6, 1979, observed:

> The world . . . may be a lot different when exploitation is proven feasible on a commercial scale, and that common heritage may mean something completely different then . . . . The definition of the Law of the Sea is being hammered out in the implementation of the exploitation of the natural resources . . . . Unlike the Law of the Sea, where we do have some information on the investment required where we do have technology and facilities . . . that can harvest the resources [of the seabed]. We're a long way from that in space activities. . . . So . . . it should not have a definition at this time. I don't think we know enough in a space context to try to define it. *International Space Activities, 1979: Hearings Before the Subcomm. on Space Science and Applications of the House Comm. on Science and Technology*, 96th Cong., 1st Sess. 96-97 (1979) [hereinafter cited as *Int'l Space Activities*].

40. 105 CONG. REC. A1822 (1959).

ing principles, the facts and circumstances may require a more institutionalized arrangement. Establishment of an international agency or authority, with defined powers and procedures[41] to govern exploitation of the natural resources of the moon, should provide a needed control on behalf of all States. It would also serve to protect the biosphere[42] and the existing balance of the environment as well as assure equitable sharing in the benefits derived from the exploited resources.

The esteemed Honorary Director of the International Institute of Space Law and founder of the Association of United States Members of the International Institute of Space Law, Mrs. Eilene Galloway, in recent testimony during a U.S. Senate subcommittee Hearing on the TOM observed:

> The problem posed by the Moon Treaty is how to translate general guidelines that express value judgments into practical arrangements for the operation of scientific and technical facilities. And beyond that, how should fair arrangements be worked out between national and international relationships?[43]

B. The Role of the International Regime

It will be in the international regime, and appropriate procedures, agreed upon in the contemplated subsequent international agreement[44] that will ultimately determine the breadth of the TOM's CHM and equitable sharing principle. While this agreement may be extremely difficult to conclude,[45] deferment of mak-

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41. *See* Menter, *Legal Regime of International Flight.* PROCEEDINGS OF THE 21ST COLLOQUIUM ON THE LAW OF OUTER SPACE 126, 130-132 (1978). (This reference is to a discussion of utilizing the International Civil Aviation Organization (ICAO) as an model for future international control of space flight).

42. *See* TOM, *supra* note 1, art. 7, para. 1.

43. The *Moon Treaty Hearings*, *supra* note 29, at 179.

44. While the language in the TOM is not explicit as to a subsequent separate treaty, the negotiated history has several such recitals. For example, in his statement to the COPUOS Legal Subcommittee concerning the natural resources of the moon under the proposal advanced by the U.S. relative to exploitation of the natural resources of the moon, Herbert Reis, the U.S. Representative to the Subcommittee, observed: "Finally, we would need to contemplate a special treaty-drafting conference in the event of the discovery of commercially exploitable resources. . . ." A similar recital for a separate treaty was also made by Ambassador Richard W. Petree in his remarks on Nov. 1, 1979 to the U.N. General Assembly Special Political Committee, *supra* note 28, at 6.

45. Aside from the nature and procedures to be determined, there will be many other matters to be considered. For example, should benefit sharing be extended to activities to which the exploited resources are applied? If so, should a space station utilizing moon materials in its construction and operation be included? Does it extend to raw products and finished manufactured items from such space station? It should be noted that in response to

ing the determinations involved permits, at this time, the acceptance of the TOM principles and direction for international cooperation in undertaking activities on or about the moon, including research and development efforts for new products and processes, space stations and habitats and ascertainment of the feasibility of commercial exploitation of the natural resources of the moon. It is to be hoped that data will be forthcoming to provide a firm basis for specificity as to the type of international regime to be established and for defining the equitable sharing in exploitable resources.

It has been the reported position of some States and attorneys that exploitation of the natural resources of the moon would not be lawful under the present state of Space Law.[46] The doubt that has existed as to lawfulness of exploitation of the moon's resources will be removed by the TOM's providing for such exploitation. It is to be hoped that this provision will encourage private sector investment in such endeavors. The need to encourage such investment has been noted as a must item for subsequent conferences seeking to establish the international regime.[47]

VI. PROPERTY RIGHTS ON THE MOON

A. General Prohibition

It may be noted that under the text of then Article X of the draft TOM, as adopted in 1973 by the COPUOS Legal Subcommittee Working Group, the wording of paragraph 2 read in pertinent part: "Neither the surface of the moon, nor, subject to the provisions of Article V, paragraph 2, their parts and natural resources shall become the property of any State, international intergovernmental or non-governmental organization, national organization or non-governmental entity, or any natural person."[48]

The referenced Article V, Paragraph 2, was to expressly authorize "the right to collect on and remove from the moon

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a question by Senator Stevenson, during previously referred to Hearings on July 29, 1980, as to whether exploitation benefits would extend to a space station not on the moon, the Legal Adviser of the Department of State, Robert B. Owens, advised that it would not as the Moon Treaty took express note of the COPUOS interpretation that space objects in earth orbit only are not within the TOM (*See* Report of the COPUOS, *supra* note 14, at 11, para. 63).

46. *The Moon Treaty Hearings*, *supra* note 29 at 9 (statement of Robert B. Owens).

47. Reis, *supra* note 24, at 6.

48. COPUOS Legal Subcomm., *supra* note 25, at 19.

samples of its mineral and other substances," and, "in the course of scientific investigations also use minerals and other substances of the moon in quantities appropriate for the support of their missions."[49] It is apparent from the above quotations that the sole exploitation to be permitted was the removal of samples, and additional amounts of minerals and other substances appropriate for the support of scientific missions.

B. The Exploitation Exception

1. THE U.S. "IN PLACE" AMENDMENT

To ensure that the above phraseology would not preclude exploitation, removal and ownership of exploited resources for other than scientific investigation, the U.S. Delegate at the 1973 Legal Subcommittee session, on April 17th, advanced an amending proposal to have the opening sentence of the above quoted then paragraph 2 of Article X, read: "Neither the surface nor the subsurface of the moon or other celestial bodies, nor *any area thereof or* natural resources *in place* shall become the property of . . . " etc. The deletion of the phrase "subject to the provisions of Article V" eliminated the limited authorization for removal of only samples and mineral and other substances in support of scientific investigations. The addition of the words "in place" was explained by the U.S. Representative at the Subcommittee session: "to indicate that the prohibition against assertion of property rights would not apply to natural resources *once reduced to possession through exploitation* either in the preregime period or, subject to the rules and procedures that a regime would constitute, following the establishment of the regime . . ."[50] (emphasis added).

The U.S. amendment was accepted and such recital constitutes Article II, paragraph 3 of the TOM. While a reader without knowledge of the negotiated history may question that the paragraph reflects authority to exploit and to own resources removed, such intent being clearly reflected in the negotiated history must govern.[51]

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49. *Id.* at 50.

50. *Id.* at 16. This was the April 17, 1973 U.S. proposed amendment to the then Article X, TOM. To explain the words "in place," see Hosenball, *The United Nations Committee on the Peaceful Uses of Outer Space: Past Accomplishments and Future Challenges*, 7 J. SPACE L. 95, 103 (1979).

51. Vienna Convention on the Law of Treaties, *supra* note 30, at art. 31, para. 4; art. 32.

2. APPLICABILITY TO THE PRIVATE SECTOR

As the words "non-governmental entity or any natural person" were in the enumeration immediately following the insertion of the words "in place", the exploitation authorization and resulting ownership authority conveyed would appear to equally extend to the private sector, subject to requirements elsewhere in the TOM such as "only under the authority and continuing supervision of the appropriate State Party" recital of Article 14. This, however, is not an onerous limitation since all enterprises are required to meet applicable legislative regulatory government agency directives, for example, licensing and supervision of commercial air carriers, and coal mining.

C. Assurances to Industry

Industry need not fear an uncertainty premised on the assertions of some critics of the TOM that there is a moratorium on exploitation of the moon's resources. This apprehension is nurtured by a strained construction of Article 11, paragraph 5 which recites that States Parties "hereby undertake to establish an international regime . . . to govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible." The negotiated history of the TOM, by recitals in the official record of the COPOUS and of the UN General Assembly, confirm that no moratorium is intended. Specific proposals for a moratorium in the course of the negotiations failed to obtain the required consensus. The consensus finally achieved on the last day of the COPUOS 1979 session resulted from a compromise in which the more limited CHM recital was accepted upon an express withdrawal of a proposal calling for deferment of exploitation pending the establishment of an international regime to govern such exploitation.[52] The UN General Assembly, in its Resolution[53] commending the TOM and requesting that it be opened for signature at the UN, took specific note of the recital in the 1979 COPUOS Report that "the Committee agreed that Article 7 is not intended to result in prohibiting the exploitation of natural resources which may be found on celestial bodies other than the earth . . . ."[54]

52. Press Release, *supra* note 35, at 7; Hosenball, *supra* note 50, at 100.

53. TOM, *supra* note 1, at 1.

54. Report of the COPUOS, *supra* note 13, at 11, para. 65.

VII. COMMERCIAL SPACE ACTIVITY

A. General

As previously indicated, several provisions of the TOM and the prior OST pertain to space activity by the private sector. While the TOM applies to activities relating to the moon and other celestial bodies, and to orbits around and other trajectories to or around them, the OST also includes all other space activities.[55] In the latter, the private sector generally would not be concerned with the TOM CHM and international regime limitation problems. However, both the TOM and prior space law treaties impose obligations and provide benefits to the private sector. The following discussion concerns the relationship between the private sector and government in their space activities, including obligations and benefits. Recitals herein shall include referral to the OST and other space law treaties believed appropriate.

B. Government Responsibility for Commercial Sector in Space

Both the TOM and the OST provide that Parties to the respective agreements shall bear international responsibility for "national activities" on the moon whether such activities are carried out by governmental agencies "or by non-governmental entities," and for assuring that national activities are carried out in conformity with the provisions of the international agreements.[56] These articles are designed to ensure responsibility for space activities, inherently international in nature, at the governmental level. The OST and the Convention on International Liability for Damage Caused by Space Objects[57] are concerned with damage caused by space objects, but have limited application to damage occuring on the Moon. This is recognized by the TOM, which envisages future consideration of further liability principles being formulated during the later review conferences contemplated of the TOM.[58]

Compensation for injuries or damages may be presently available under a State's domestic legislation. In the United States, authority is provided the Administrator of NASA and the

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55. OST, *supra* note 2, at art. 1.
56. TOM, *supra* note 1, at art. 14, para. 1; OST, *supra* note 2, at arts. VI, VII.
57. *See* note 2, *supra*.
58. *See* TOM, *supra* note 1, at art. 14, para. 2.

Secretaries of the military departments to administratively settle claims arising out of space activities.[59]

C. Jurisdiction and Control of Personnel and Objects in Space

Each State Party to the TOM retains "jurisdiction and control" over its nationals, their space vehicles, equipment, facilities, stations and installations on the moon.[60] Similar jurisdiction under the OST over an object launched into outer space and the personnel (including foreigners) abroad, on a celestial body or otherwise in outer space, is retained by the State on whose registry the launched object is carried.[61] This imposes on a State the requirement to ensure that it possesses the necessary legal authority to exercise such jurisdiction and control. Of course, the State of Registry could waive its jurisdiction in a particular case where another State, under the international law, may also have jurisdiction. Under the "nationality principle," a State may extend its jurisdiction over offenses by its nationals wherever they occur.

A sovereign is obligated under international law to protect its own and foreign personnel lawfully under its jurisdiction. The U.S. Congress is considering enactment of legislation to extend U.S. criminal jurisdiction over offenses committed aboard U.S. launched spacecraft and at places otherwise "outside the jurisdiction of any nation" where the offenses are committed "by or against a national of the United States."[62] This jurisdiction, of course, would embrace offenses on the moon or otherwise in outer space. While more specific recitals in the U.S. Criminal Code are

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59. Claims to $25,000 may be settled within the agencies; claims above $25,000, deemed meritorious, may be certified to the U.S. Comptroller General or to the Congress for payment consideration. 10 U.S.C. §§ 2733, 2734 (1976).

60. TOM, *supra* note 1, at art. 12, para. 1.

61. OST, *supra* note 2, at art. VIII.

62. S. 1722, 96th Cong., 1st Sess. (1980). The proposed "Criminal Code Reform Act of 1980" was favorably reported out of the Senate Judiciary Committee, with amendments, on January 17, 1980. Its House counterpart, H.R. 6915, 96th Cong., 2nd Sess. (1980) was favorably reported out of the House Judiciary Committee on July 2, 1980. While the short time remaining of the 96th Congress precluded resolution of differences between the Senate and House versions before adjournment the measure is certain to be reintroduced with likely enactment by the 97th Congress. A new, more limited measure is already under consideration as the "National Aeronautics and Space Authorization Act, 1982." H.R. 1257, 97th Cong., 1st Sess. (1981). This measure includes a proposed amendment to 18 U.S.C. § 7 (1976), by adding a subparagraph 6 thereto, to extend the Special Maritime and Territorial Jurisdiction of the United States to space flight. For a discussion of this possible approach, *see* Menter, *Jurisdiction Over Man-Made Orbital Satellites*, 2 J. SPACE L. 19, 22 (1974).

being sought, the NASA Administrator, under authority delegated to him in the National Aeronautics and Space Act of 1958,[63] as amended, on March 7, 1980, issued regulations vesting "absolute authority" in the Commander of the Space Shuttle to enforce order and discipline during all phases of a Shuttle flight, including authority to take action believed necessary for the protection, safety, and well-being of all personnel and on-board equipment and payloads.[64] A violation of the Shuttle Commander's orders would subject the offender to a fine of up to $5,000 or imprisonment for one year, or both.[65] Further note is made that under existing U.S. law pertaining to active duty military personnel, such personnel are subject to U.S. jurisdiction under the Uniform Code of Military Justice for offenses committed thereunder wherever performing assigned duties.[66] The above recitals, of course, also embrace personnel of the private sector participating in space activities.

D. Ownership of Property in Space

Under Article 12 of the TOM, the private entrepreneur retains ownership of his space vehicle, equipment, facilities, stations and installations on the moon. Such property and personnel of the employer are to be accorded the benefits provided astronauts by Article V of the OST[67] and provided for space objects by the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched Into Outer Space.[68] Thus, if under the stated circumstances, personnel or property of a private company is found by another State Party to the TOM in other than its intended location on the moon, it should be rescued and returned to the responsible State or its representative. The latter State is to bear the expenses incurred in recovery and return of the property.[69] In the event of an emergency involving threat to the lives of such personnel, they may use the facilities and equipment of any State Party on the Moon.[70]

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63. 42 U.S.C. § 2455(a) (1976).
64. 45 Fed. Reg. 14,845 (1980) (to be codified in 14 C.F.R. § 1214.7).
65. 18 U.S.C. § 799 (1976).
66. 10 U.S.C. § 802 (1976).
67. TOM, *supra* note 1, at art. 10, para. 1.
68. Return of Astronauts Agreement, *supra* note 2, at art. 5.
69. *Id.* at art. 5, para. 5.
70. TOM, *supra* note 1, at art. 10, para. 2; art. 12, para. 3.

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VIII. THE ERA AHEAD: OBLIGATIONS AND OPPORTUNITIES

A. Equity Responsibilities

The moon and its natural resources are recited in Article 11 of the TOM as the CHM. Yet under the TOM, neither mankind, nor all States are entitled to share in the benefits of exploitation. The 'equitable sharing' is provided only for State Parties to the TOM. Such States are expressly precluded by paragraph 3 of Article 11 from having property rights in either the surface or subsurface of the moon. Ownership is provided over natural resources of the moon only when no longer "in place." Such ownership accrues to the successful exploiting State. The equitable sharing provided for is not of the resources exploited, nor a division "of" the benefits derived from the resources. Only a sharing "in" the benefits derived "from" the resources are required. This appears a more limited concept than mankind's common ownership of the moon and its resources.

Black's Law Dictionary defines "equitable," in part, as "just, fair and right, in consideration of the facts and circumstances of the individual case."[71] The Dictionary narrates that Justinian is said to have defined 'equity' as "to live honestly, to harm nobody and to render every man his due."[72] While the subsequent agreement for an international regime may establish criteria, it is conceivable that the share "due" to a non-contributing State may be determined to be zero. However, whether the OST concepts or a formula for a greater sharing in the benefits will govern must await the subsequent treaty. If a State Party to the TOM does not accept the subsequent treaty, it nevertheless remains obligated in carrying out its activities with the respect to the natural resources of the moon to do so in a manner compatible with the purposes sought by the international regime specified in Article 11, paragraph 7, of the TOM, including the "equitable sharing" principle.

In a recent presentation, Dr. Stephen Doyle, Program Manager for Telecommunications, Information and Space Studies of the Office of Technology, U.S. Congress, characterized the most recent of the evolutionary phases of Space Law as the "extrater-

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71. BLACK'S LAW DICTIONARY 482 (5th ed. 1979).
72. *Id.* at 484.

restrial law phase." He marks its beginning with the UN General Assembly promulgation of the TOM in December 1979. The implementation of the new regime of "common heritage" is recited as a "major problem that will demand the best and most creative of our skills." He observed that the 19th century model of exploration and conflict cannot be tolerated in the 21st century. He states however, that "it must be understood that if there is to be no dominion by a few countries, there must be no dominion by the majority. . . ." "Equity" is stated as the "key concept" for realizing the use and benefit of space which is to be available to all nations regardless of their levels of economic development. "But that," Dr. Doyle states, "should not be read to mean that every nation has a right to share equally in benefits regardless of contribution." He further observed that "opportunities must be nondiscriminatory and there must be a possibility for all to contribute to and share in endeavors in space. Returns, however, must reflect contributions. There is no 'free lunch'."[73]

B. Private Sector Investment Encouraged

In the recent Congressional hearing on U.S. Civil Space Policy, the President of the Northrop Corporation, Dr. Thomas O. Paine, a prior Administrator of NASA, narrated successful past and present ventures of private enterprise in space activities. He urged establishment of goals for the future, observing:

> Private enterprise has now raised and invested more than $1 billion in orbiting comsats, with a growth trend that indicates doubling in the next few years. In similar fashion, satellite remote sensing has grown . . . , initiating another new space industry[74] . . . , the routine conduct of opportunistic research in laboratories in space is an activity whose time has come . . . . We need to explore new ideas that utilize the availability of unlimited energy, ready sources of lunar and asteroidal materials[75] . . . . Now is the time to plan and initiate work on the essential initial orbiting bases.[76]

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73. S.E. Doyle, Significant Developments in Space Law: A Projection for the Next Decade (April 21, 1980) (a paper presented at the University of Mississippi Law Center Symposium on "Space Law in Perspective").

74. *United States Civilian Space Policy: Hearings Before the Subcomm. on Space Science and Applications of the House Comm. on Science and Technology*, 96th Cong., 2nd Sess. 9 (1980) (statement of Dr. Thomas O. Paine).

75. *Id.* at 13.

76. *Id.* at 14.

Dr. Paine further testified that we should continue to promote international participation in major space ventures as a positive step in maintenance of peace among the major powers, the further application of space systems to raise living standards around the world, and the sharing of costs and benefits of space activities among all countries.[77] Mr. S. Neil Hosenball, the General Counsel of NASA, chaired the U.S. Delegation to the 1979 COPUOS session. In testifying in House of Representatives Hearings on "International Space Activities, 1979," he observed that a review of the total records of the TOM negotiations over seven years clearly establishes that there has not been any limitation imposed on the commercial exploitation of the lunar surfaces or celestial body resources and that "nothing in the treaty in any way restricts such activity being carried out by industry, by private commercial entities."[78] Recitals of the Treaty have been categorized as "incentives" by Ambassador Richard W. Petree, U.S. Deputy Representative to the UN Security Council. He observed that by setting forth in Article 11, paragraph 7, the purposes governing exploitation of natural resources, "uncertainty is decreased and both State and private entities may now find it possible to engage in the arduous and expensive efforts necessary if exploitation of the natural resources is ever to become a reality."[79]

C. Clarification of "Equitably Sharing"

The difficulty and importance to the international community of attaining the later agreement for an international regime is apparent. Realism would suggest a pragmatic approach by all interests. Without adequate inducement to States and, where applicable, to their "non-governmental entities" concerned, the effort to determine feasibility of moon resources exploration will falter. In countries where the private sector plays a predominant role in industrial production on a profit basis, such sectors must be assured that the risk is reasonable and within permissive limits.

It is believed that the early fears expressed by the private sector have been exaggerated. Nor should a requirement to share profits, should such extreme determination be within the authority of the international regime, itself be the sole basis of the private sector's refusal to advance risk capital in a national

77. *Id.* at 16.

78. *Int'l Space Activities*, *supra* note 39, at 95 (testimony of S.N. Hosenball).

79. Press Release, *supra* note 35.

endeavor for exploitation of the natural resources of the moon. U.S. industry has not declined participation in foreign government ventures with sharing of profits in high risk situations, such as in petroleum endeavors, viz: oil drilling, exploration, processing or refinement, production and distribution. Neither has it declined to risk capital in payment to the United States for leases to explore for oil in US owned lands, including seabeds and mountain shale, or for mineral rights exploration.

As previously indicated, it will be many years before exploitation of the moon's resources becomes feasible. It is reasonable to assume that costs involved would be recouped before any equitable sharing may begin. At the later exploitation stage, could not the sharing of profits be construed as a condition for participation in the project similar to the referenced foreign petroleum ventures, or as an overhead cost akin, in part, to overhead rental for the exclusive moon area utilized. As such exploitation is a national activity under the TOM, should not some tax considerations be accorded by the sponsoring government?

D. Government-Industry Cooperation

The great success of the United States space effort has been based upon the close cooperation between Government and industry. The Government policy is to retain a major space research and development endeavor until it becomes commercially feasible. Turnover to the private sector at that time would not necessarily terminate further research and development by the Government in such area. While the Government funds its research program, it calls upon industry to share in concept development and to produce and test necessary hardware.

In the development of a national capability to exploit the moon's resources, Governments will employ their industrial capability to achieve their goals. Costs therefore will primarily be borne by Government whether functioning through governmental or non-governmental entities. Additional incentives to industry may be manifold, *e.g.*, study grants, cost plus payments, and loan guarantees. In a recent legislative proposal, for example, Congressman Donald Fuqua, Chairman of the Committee on Science and Technology of the House of Representatives, has proposed legislation to encourage private sector interest in space activities participation. This measure, H.R. 7412, 96th Congress, 2nd Session, introduced on May 21, 1980, sought to establish a "Space In-

dustrialization Corporation" to provide Government secured investment capital for high technology space ventures which otherwise may exceed acceptable risk to private sector elements.[80]

Chairman Fuqua has recently written that prospects for further improvement of goods and services "will move nations to expanded uses of the space environment that will reap countless economic and societal benefits."[81] He further observed: "We are on the threshold of industrializing space and the role of private enterprise will determine the success of these endeavors . . . ."[82]

E. Government Leadership and Support

Nations in the past, whatever their ideology, have not hesitated to bear the majority of, if not all, expenses incident to desired high risk endeavors. Where private enterprise exists, governments have tailored legislation on the subject concerned as an inducement for private sector participation (*e.g.*, in shipping, railroading, air carrier transportation, and atomic energy).

In the United States, both the Executive and Legislative branches of the Government are currently evaluating concepts to induce private sector participation in space activities. It is incumbent upon the private sector to advise the Government of its interests, capabilities and limitations as specific activities are addressed (including, should the U.S. become a Party to the TOM, recommendations for the future treaty to provide an international regime to govern exploitation of the natural resources of the moon). The Government in turn must assure industry protection from unacceptable risk until economic feasibility is apparent.

F. U.S. Consideration of Acceptance of the TOM

While U.S. leadership was the moving force in the UN's

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80. H.R. 7412, *supra* note 11, was introduced on May 21, 1980 by Congressman Fuqua for himself and fifteen others. It was to have been cited on enactment as the "Space Industrialization Act of 1980." The bill provided for the establishment of a Space Industrial Corporation to promote new products, processes, services, and industries using the properties of space technology. The measure sought to provide a high degree of assurance that the private entity could depend upon security in handling competitive information, private ownership of patent and proprietary data, and the ultimate sharing in the benefits of the competitive venture. H.R. 7412 was a successor bill to H.R. 2337, 96th Cong., 1st Sess., also introduced by Congressman Fuqua.

81. Fuqua, *Space Industrialization: Some Legal and Policy Considerations for Private Enterprise*, 8 J. SPACE L. 1, 2 (1980).

82. *Id.*

favorable consideration and endorsement of the TOM, it is probable that the contending interpretations discussed above will preclude the U.S. from becoming a Party at the time of the TOM's entrance into force. The caution of private industry towards commitment of substantial capital in risk ventures before clear resolution of contending issues in exploitation of the moon's natural resources is recognized. Involved are questions of the validity of exploitation, title to (ownership of) exploited resources, possible sharing (CHM) of resulting benefits, role and time of coming into effect of the proposed regulatory regime, and the obligation of private sector participants if the international regime is not established.

Granted that the wording of the TOM raises serious questions as to interpretation, it is believed that the negotiated history of the TOM does substantiate the meaning intended by its drafters which accords with the prior Space Law treaties and is in the interest of U.S. private enterprise and the world community.

To assure that the issues raised are consistently resolved in accord with the meaning of terms and intent reflected in the negotiated history, the author suggests that the U.S. in actions supporting the TOM—such as in signing the TOM and/or during the Senate ratification process—should set forth its written "understanding" of each of the contending issues with reference to the negotiated history substantiating its conclusions. These "understandings," under customary international law as well as under the Vienna Convention on the Law of Treaties, are considered as reservations.[83] Thus, an objection by another State adherent must specifically reject the U.S. recital of understanding to preclude entrance of the Treaty into force between them. If no such objection is made within one year, the U.S. understanding is deemed accepted.

G. For All Mankind

In the interests of avoiding seeds for conflict encountered through history on Earth, the world community tailored the OST to a new set of legal principles proclaiming outer space and its celestial bodies as the province of all mankind and that its exploration and use shall be carried out for the benefit of all peoples.

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83. Vienna Convention on the Law of Treaties, *supra* note 30, at art. 19; art. 20, paras. 4(b), 5; art. 23.

Space activities, since the OST came into force in 1967, have brought great benefits to the world community. The private sector has participated and profited. It is believed that rather than limit private sector opportunities, the TOM will enhance them by opening new vistas with rewards, as in the past, dependent upon initiative, ingenuity and industrial capability, with government support tailored to high risk endeavors.

Continued international accord is essential for preventing friction in space. This is of equal concern to all States. Greater participation of non-space powers in space activity should better ensure bringing to fruition its many benefits for all mankind. Such cooperation should further assure peaceful coexistence in space and on our Spaceship Earth.

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COSMIC COUNSELOR

By Ron Bitto

OMNI PROFILE

International law could block space efforts by private enterprise — but not if lawyer Art Dula has his way

After meeting Art Dula, it's easy to picture him 25 years from now. Seated in a geodesic lunar courtroom, his ample figure lends an authoritative bulge to his judicial jump suit. He leans forward on the bench and begins his history lesson. Space law, he points out, traces its roots to the Corpus Juris of the Roman Empire. The two lawyers he's lecturing have heard it before, but they listen respectfully to the moon's first federal jurist. Then Judge Dula reads his decision, settling a corporate dispute over molybdenum mining in the Sea of Tranquillity. He allows extraction to begin immediately.

Today, at thirty-three, Arthur M. Dula is a blend of technologist and legal historian, an ardent advocate of free enterprise who looks to the past for guidance and to the future for vast new opportunities. He is probably the first private attorney in America to devote his practice solely to aerospace and technical law.

Dula's office occupies the second floor of a restored Victorian house in Houston's Heights, an inner-city neighborhood slowly being redeveloped. A topographical map of Mars hangs behind his massive desk, above his right shoulder. He talks enthusiastically into the telephone. To burn off nervous energy, he pulls an ivory-handled .45 automatic from the desk drawer, removes the clip, and lines up the cartridges on

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his blotter like a row of tin soldiers. Then he reverses the process, slowly reloading the gun and returning it to the drawer.

Last week a delegation of European lawyers attended a seminar on technical law that Dula conducted at Louisiana State University Law School. During the course he promised them a tour of the Johnson Space Center, in Houston. Today he is phoning one of his many contacts at NASA to arrange the visit.

"We've got to impress them with the space program," Dula asserts repeatedly. "We've got to show that America is serious about putting business into space. These guys are from Europe's biggest banks and financial institutions. Can't we arrange for something off the public tour to make them feel special?"

Dula's friend bends a few rules to set up a Saturday tour.

While Dula often sounds like a self-appointed public-relations man for the American space program, his true vocation lies not in promoting NASA but in helping companies solve the legal problems of introducing new technology and making a profit from it on Earth and in space.

Dula's practice is wide-ranging. A few of his clients are earthbound. One is a Mexican company trying to introduce a new windmill to the United States. Another has developed a way to produce electricity and fresh water from ocean waves. And a client on the East Coast has a chemical process that turns wood chips directly into ethanol, eliminating the energy-intensive distillation now used to produce gasohol.

But several of his clients hope to profit from space itself. Dula acts as a patent lawyer for Eric Drexler, who has invented an improved solar sail. And he represents a company that has developed a new type of rocket engine. He also works for a group of businessmen interested in launching a private space vehicle.

Often his clients' space technologies offer benefits for life on Earth. One company Dula represents has developed a way to refine moon rocks and extract such elements as oxygen, silicon, aluminum, and titanium. "Lunar material seems an awful lot like the fly ash collected in precipitators at coal-fired power plants," the Texas attorney points out. "Every year, electric utilities in this country collect enough of this ash to fill the Grand Canyon. This technology could turn one of our most noxious wastes into a valuable resource."

"The more I get involved in high technology," he notes, "the more I see this synergy between aerospace and Earth. Technology developed for space almost always has benefits on Earth."

Dula's clients take up only part of his time. Much of the rest he spends as a legal theoretician, writing about laws that could enable business to operate profitably in space. Dula sees a bright future for mankind beyond Earth's gravity.

"The great fortunes of the next century will be made in the asteroid belt," the attorney maintains. By the year 2020, "a significant fraction of humanity's gross world product will be derived from space-based activities."

Transportation to Earth orbit will be routine and inexpensive by then, he expects, and solar-sail spacecraft will routinely traverse the inner solar system. Mature businesses will manufacture goods, generate electricity, and gather information in orbit, while private enterprise will be exploiting asteroidal minerals that are processed in orbit.

"Once profit—that is, new, real wealth—begins to flow back to Earth," Dula projects, "investment in space operations will accelerate as world corporations go after profits greater than those possible on the postindustrial Earth."

"Unfortunately, the laws that govern technology—and particularly space law—are evolving at a much slower pace." That leaves many gray areas where the law has not been set. And to Dula, these ambiguities are more than dry legal theory. They could, he believes, discourage investment in space. At least one might even block space development by private enterprise entirely.

"Unless we develop some practical laws to govern our activities in space, we shouldn't be surprised when war breaks out over who has the right to develop the solar system."

Part of the problem lies with NASA itself, Dula feels. In 1978 he wrote a report for the agency detailing the ten most important factors inhibiting participation in the shuttle program by nonaerospace companies. Most were rooted in the NASA Act, our national space law.

For example, NASA controls America's only launch facilities and has discouraged the development of private booster systems. The agency retains all patent rights to technologies developed in operations that involve it in any way, and its administrator can reveal any trade secrets used in experiments on the shuttle. This alone is enough to keep many companies that rely on unique technology from launching experiments on the shuttle.

And Dula believes that NASA's charter discourages cooperation with companies other than the aerospace giants. The agency is set up both to promote space activities and to regulate them. In short, concerns that deal with NASA tend to become captive industries.

Moreover, NASA's policy has been to concentrate on the academic and military use of space, playing down commercial possibilities. Communications and weather satellites—the two areas where space technology is improving life on Earth and doing so at a profit—are outside NASA's jurisdiction. They are handled by Comsat and the National Oceanographic and Atmospheric Administration, respectively.

By neglecting commerce while working closely with big aerospace contractors, NASA has failed to tell potential shuttle customers about the opportunities in space. Dula proposes to remedy this with a more aggressive public-relations program for NASA. He also suggests teaming nonaerospace companies with experienced space contractors to help the newcomers deal effectively with the agency.

Dula's concern with such issues is an old one. Robert Heinlein's science fiction convinced him long ago that mankind should not be limited to its home planet. Heinlein's works even influenced his choice of schooling. "I agree with Mr. Heinlein," Dula says, "that anyone who doesn't understand math ought to learn it. It's basic to understanding the universe." And in a technical society, he knew, even a lawyer needs a strong background in science. So as a prelaw student at Eastern New Mexico University, Dula majored in chemistry and took his minor in mathematics.

He has since built a collection of Heinlein first editions, and the science-fiction art that lines his office includes a watercolor by Ann Layman Chancellor depicting the opening scene of Heinlein's novel *Citizen of the Galaxy*. "Heinlein himself saw the picture at an art show and recognized it as the scene from his book," Dula remembers with a smile.

Leaving New Mexico, Dula went to Tulane University's law school, in New Orleans, where he made the law review. He retained an ambition to manufacture starships, but he also gained a deep interest in Earth's legal traditions. Today his science-fiction library shares a room with a collection of ancient lawbooks.

This interest in the history of law clearly marks Dula's approach to space law. "The Romans gave nations jurisdiction over their territory from hell up to the sphere of the fixed stars," Dula points out. "That's where we get our concept of airspace. So the Roman Code is really the starting point for laws governing space."

But a more recent episode of history has even clearer implications for space development, Dula feels. "Whenever academic laws have been arbitrarily projected into the future," he says, "there have been disastrous consequences. When Pope Alexander the Sixth drew the Line of Demarcation in the year 1494, dividing the New World between Spain and Portugal, he left out England and France. The result was decades of war over the ownership of the

resources of the Western Hemisphere."

The Texan worries that similar confrontations may be built into today's international space law. "Unless we develop a practical law governing activities in space, we shouldn't be surprised when war breaks out over who has the right to develop space resources," he warns.

Current space law prohibits the "occupation" of space. Such permanent establishments as space stations and lunar mining facilities would therefore violate international treaty. The geosynchronous orbits a solar-power-satellite (SPS) system would require — now nearly filled by military and communications satellites — also violate this prohibition.

Partly because of this ban, there is no accepted way to assign "grazing rights" to orbits in space. Eventually the most desirable orbits will become filled. At that point it isn't hard to imagine that a power with killer satellites might decide to clear private craft out of the positions it needs. Investors would find "range wars" in space a difficult hazard to accept.

But the threat that worries Dula most is already in progress. "The one thing that could stop the development of space by free enterprise would be to outlaw making a profit in space," he says. "The Soviet Union and Third World countries are now attempting this through the Moon Treaty."

The 1967 Treaty of Principles and the Moon Treaty under debate in the United Nations — and signed but not ratified by the United States — proclaim that the resources of space are the common heritage of all mankind. This is a lofty-sounding principle, but it is vague. Neither treaty spells out exactly how this heritage is supposed to be divided.

If ratified, the Moon Treaty would forbid private ownership of minerals on the moon and on other "celestial bodies." But without ownership, there can be no profit. And as Dula points out, "free enterprise does not move where there is no profit."

"Unfortunately, international space law is based on academic and dangerous treaties designed to chill the development of free enterprise in outer space. Space may be the common heritage of all mankind in a philosophical sense, but the resources actually developed by private industry must belong to the entrepreneur who had the vision and took the risk to obtain the benefit."

And that risk, incidentally, should all be on the company's shoulders. Yet the treaty on international liability for damage caused by space objects states that national governments have infinite liability for damage caused by objects launched from their country.

"Pan American World Airways flies everywhere in the world," Dula reminds us, "with vehicles bigger and heavier than the space shuttle. Their planes would do more damage if they crashed. Yet no one seems upset because Pan Am stands liable for its own damage." The attorney feels that

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COUNSELOR

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space vehicles should be covered by current insurance law just as air transport is. "There's no reason for the government to take on that kind of liability for private companies," he says. "But by signing that treaty, the U.S. government has gratuitously done so."

Dula's list of legal obstacles to space development is a long one. Look at SPS units, for instance. They are technically feasible and might be economical if built in space from lunar materials. Dula himself thinks the tangible benefits of an SPS program could restore public support for space development. Yet at every step there are legal questions to be answered. According to international treaty, space vehicles, like ships, must be registered to a single nation whose laws govern the craft in space. For an American spacecraft ferrying workmen to build an SPS system, federal law would become space law. But whose regulations would govern a space station owned by a multinational corporation, manned by people from many countries and building SPS units for several different parts of the world? Here the law is not at all clear.

When the first SPS goes into operation, still more legal questions will emerge. Does the power belong to all mankind or to the corporation that collects it? And once the system makes a profit, must the taxes be divided among all governments to ensure a fair distribution of the benefits from outer space? No one knows.

"Existing space law is extremely vague, and it is stacked in favor of the Soviet Union and the Third World countries," Dula warns. "This trend must be reversed before a viable commercial space industry can evolve."

Dula has been involved with technical issues from the beginning of his career. As a young patent lawyer with the large Houston firm of Butler, Binion, Rice, Cook, and Knapp, he worked for industrial clients in the medical and aerospace fields. He soon saw the need for a new breed of lawyer, one who could devote himself entirely to the legal questions presented by advanced technology.

Dula first established himself as an expert on the legal aspects of medical physics, then became a faculty member at the University of Texas Medical School and the University of Houston's Bates College of Law. During the same period, he served in the American Bar Association's Science and Technology Section, of which he is now chairman-elect.

After conducting studies for NASA and General Dynamics on the prospects for development of private industry in space, Dula opened his practice in aerospace and technical law in December 1979.

Technologically, Dula claims to be five years ahead of the big law firms. His office is equipped with a modern computer system that tracks his clients' legal activities; his legal papers are turned out on a word processor. His big house is cooled by an advanced heat pump that uses far less energy than ordinary air conditioners.

On the same day that Dula formed his law firm, he became secretary-treasurer and general counsel for Eagle Engineering, a small consulting firm he founded with three engineer-managers formerly with NASA. Eagle applies the technical and managerial skills acquired in the space program to problems encountered in business and government. Eagle has designed petrochemical process equipment, has integrated computer-hardware and -software systems, and has performed technology assessments of advanced propulsion systems, the SPS, and ocean-thermal-energy systems.

Dula is also a charter member of the Space Foundation, a group of Houston businessmen working to find opportunities for free enterprise in space. At the International Aeronautics Association's conference in Tokyo last September, Dula showed *The Harvest*, a film produced by the Space Foundation. The film's thesis is that mankind is no longer limited to a single planet and that free enterprise can use presently existing technology to harvest space resources. "It raised a few eyebrows among members of the Socialist delegations, particularly that from the Soviet Union," Dula says.

He also showed slides outlining a technological assessment of the SPS. "I think the SPS presentation demonstrated to the Russians that, given the opportunity, free enterprise can operate in space and return real benefits to Earth."

In 1978 Dula ran as a Republican candidate for the Texas House of Representatives. He jokingly remembers his campaign as having been run on the "space platform." In fact, he ran a rather conventional campaign that stressed strong public schools and a comprehensive regional water plan. He lost, but he made a respectable showing in a heavily Democratic congressional district.

One evening during the campaign, he received a last-minute invitation to speak at a community center. Too short of time to prepare a new talk tailored to his audience, he decided to give his slide presentation on the SPS. "That audience was the most attentive group I spoke to during the campaign," Dula recalls. "And do you know why? Because space presents us with an optimistic view of the future, a future of growth and prosperity."

Dula has promised his wife, Tamea Ann, who is also an attorney, that they'll visit the moon together by the year 2001. If he isn't a lunar judge by then, he doesn't plan to take more than three weeks of vacation to make the trip. ∞

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VIEW OF AN INTERNATIONAL CONCERN

Militarization and The Outer Space Treaty— Time for a Restatement of "Space Law"

By GEORGE S. ROBINSON
Smithsonian Institution

For outer space to be a sanctuary from the ever-grinding conflicts on Earth, resolve and teeth should be put into this multinational accord

Disturbing developments are taking place in the arms race regarding the uses of outer space. It seems to me that a number of lawyers and statesmen involved in the ongoing development of international cooperation in space, arms control and disarmament negotiations, and the formulation of "new" space law are turning a blind eye to the extension of Earth-bound warfare technology into space and the impact of this militarism on the Outer Space Treaty of 1967.

This treaty, more properly entitled "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other Celestial Bodies," is frequently called the "Mother Treaty" by space lawyers. And quite properly so, since it embodies the international spirit and intent, as well as broad guiding legal principles, of cooperation and restraint in exploring and exploiting space in a more elevated fashion than history characterizes exploration and exploitation on Earth. The Outer Space Treaty reflected the prevailing spirit that space was to be a sort of "sanctuary" from the traditional military and economic competition among nations, and mandated that—

—Space exploration shall be conducted for the benefit of all countries, and shall be the province of all mankind.

—Outer space and celestial bodies cannot be claimed by any country for itself.

—Space research is to be carried out in the interest of furthering international cooperation, understanding, and peace everywhere.

—Outer space may not be used for the placing of nuclear weapons or other weapons of mass destruction, nor shall there be any military bases, installations or fortifications, maneuvers, or weapons testing in outer space.

—Astronauts shall be considered as envoys of mankind and shall be given assistance and protection in their endeavors.

—States, governments and international organizations shall have certain liabilities for activities and accidents arising from space exploration.

—Efforts will be made to avoid contaminating celestial bodies or harming the Earth environment as a result of the introduction of extraterrestrial matter.

—The signatory States must consult with each other when there is reason to believe a planned experiment would cause harmful interference with other activities or interests of the signatories. They must consider requests for visual observations by member states on the basis of equality regarding various activities; the purpose being to encourage international cooperation in space research.

Under this umbrella of good intentions, several treaties and agreements more limited in scope have been negotiated, and others continue to be—among them the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space; the Conven-

GEORGE S. ROBINSON has served for the past seven years as assistant general counsel of the Smithsonian Institution. Before that he was legal counsel for the FAA and an international-relations specialist at NASA. He engages in a broad domestic and international law practice and serves as counsel for many of the Smithsonian Institution's scientific research projects. A graduate of Bowdoin College (major in biochemistry), he holds an LL.B. from the Univ. of Virginia Law School and an LL.M. and a Doctor of Civil Laws degree from the Institute of Air and Space Law of McGill Univ. Robinson has written a number of articles and books on space law.

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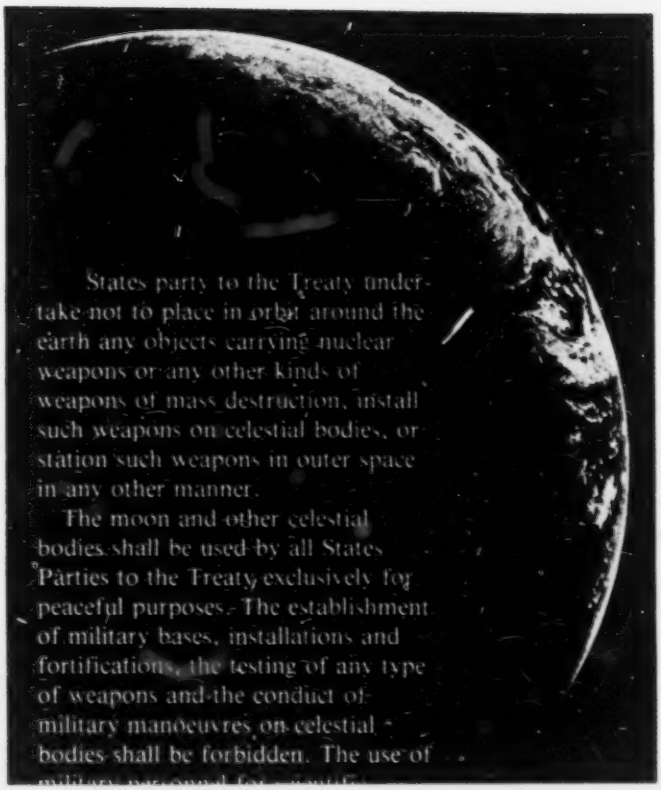
States party to the Treaty undertake not to place in orbit around the earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner.
The moon and other celestial bodies shall be used by all States Parties to the Treaty exclusively for peaceful purposes. The establishment of military bases, installations and fortifications, the testing of any type of weapons and the conduct of military manoeuvres on celestial bodies shall be forbidden. The use of

tion on International Liability for Damage Caused by Space Objects; the Convention on Registration of Objects Launched into Outer Space; and the present efforts dealing with exploitation of the Moon's surface. The most difficult issue—determining precisely what constitutes acceptable military use of space—is arising in the context of a variety of *bilateral agreements* that do not have as guiding terms of reference the positive uses of space reflected in the Outer Space Treaty: for example, the 1972 ABM Treaty limiting the use and capabilities of antiballistic missiles; the Interim SALT Agreement of 1972 limiting the use of certain strategic weapons; the 1963 Limited Nuclear Test Ban Treaty (basically limiting nuclear testing to underground).

Certainly one of the most difficult issues to resolve in negotiating the Outer Space Treaty concerned military activity in space: what activity *should* be prohibited by mutual agreement, and what in fact *could* be prohibited. It was understood and agreed by the Soviet Union and the United States during the negotiations that there would be no broad prohibition of military activities. However, based upon concern with the then-current aggressive capabilities using a space environment, the negotiators carefully formulated Article 4 of the Outer Space Treaty which provides in part that—

> States Parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner... [T]he testing of any type of weapons...on celestial bodies shall be forbidden.

Subsequent to the effective date of the Treaty, and as technological capabilities accumulated at a precipitous rate, critical words and phrases became issues of conflict in determining what is acceptable military activity: for example, precise definitions of "in orbit," "weapons," "*mass* destruction," "*celestial* bodies," and "or *station* such weapons...." Article 4 has been debated extensively in attempts to reach mutual agreement on whether certain advanced space technologies having both passive and aggressive military uses are exempted

from, or prohibited by, the Outer Space Treaty. Even the term "peaceful" has evoked several interpretations among practitioners of international law: non-aggressive, no military personnel, no hostile potential, strictly civilian personnel and potential, and the like. In any event, since 1967 new technologies and tactical philosophies have precipitated new concepts and vocabularies not anticipated in the language and provisions of the Outer Space Treaty or other international law existing at that time.

Some of the broader questions raised by Article 4 of the Treaty include these:

- Why restrict the prohibition against testing weapons only to celestial bodies?
- Are celestial bodies limited only to natural bodies or do they include synthetically fabricated platforms, such as the Shuttle and future large space habitats?
- Does the phrase "nuclear weapons or any other kinds of weapons of mass destruction" include component parts of an Earth-based weapons system, such as navigation, communications, and intelligence-gathering satellites, as well as anti-satellite weapons? If such components are not considered weapons of mass destruction, are they adequately covered by other existing international law which properly expresses *the spirit and intent* of the Outer Space Treaty regarding the "sanctuary" nature of space?
- Is there any reasonable way to distinguish between defensive and offensive military uses of space in the legal context of the right of nations to undertake actions of self-defense? And what constitutes the right to take defensive action—hostile or threatening behavior of another nation?

In terms of scientific research for "peaceful purposes," it is obvious that what is peaceful for one purpose may not be for another, and the problems surrounding *verification* of an item or activity as peaceful becomes a critical and extremely difficult issue to resolve. In fact, I see no effective legal definition distinguishing between "peaceful" and "hostile or threatening" military space activities until some overt hostile act actually has occurred. To date, verification has been considered a technological problem. Effective measures for forcing public disclosure of proposed activities have not been emphasized as viable substitutes for technological verification, nor has the increasing effectiveness of broad public opinion been considered as a workable sanction against Treaty violators, or would-be violators.

History shows us that diplomatic positions backed by military capabilities rest on prevailing perceptions of reality by policy makers, and do not flow from slavish commitment to transcending principles of peaceful good will, such as those embraced in the Outer Space Treaty. Various multilateral treaties and bilateral agreements notwithstanding, the United States and the Soviet Union are working on their respective game plans for space warfare. "Despite wishful thinking to the contrary," asserted Gen. Jacob E. Smart (Ret.) in the Fall 1974 issue of *Strategic Review*, "man is and promises to remain an aggressive, combative creature. We fear, we hate, we fight one another. Until we remove causes of fear and hatred and correct the conditions which prompt us to arm ourselves, we have no choice but to prepare to defend ourselves against attack in whatever form and through whatever media attacks may come. Today and henceforth the United States must be prepared to defend itself against aggression *in* space and *from* space. We cannot surrender the 'high ground' without contest."

There continue to be individuals who feel that one way to correct the conditions that cause us to arm ourselves is to substitute energies of a combative nature with energies needed for competitive space exploration and exploitation for the peaceful benefit of all humankind. The spirit, intent, and language of the Outer Space Treaty reflect that sentiment.

However, in the philosophic context of General Smart's remarks, it is recognizably necessary to re-evaluate from time to time what the international community perceives to be essential for world peace and security, including military capabilities in space. But must they be re-evaluated in the framework of the Outer Space Treaty, or is it proper to interpret that document through negotiations on arms control and disarmament among limited parties? Unfortunately, much of the legal interpretation of the Outer Space Treaty relating to military activities is taking place outside that document, principally on a bilateral and regional basis, among the superpowers.

The history of these limited negotiations underscores the difficulty of achieving workable legal definitions of "weapons" and "peaceful" or "aggressive" activities in space. It may well be that to achieve *peaceful* cooperation in space the prohibitions in the Outer Space Treaty of weapons of mass destruction must be expanded to include *all integral space components of a weapons system located primarily on Earth's surface.* If that amounts to disarmament, well, is not that the second objective of arms-control negotiations.

To determine, legally, whether the Treaty was intended to serve such a broad prohibition, it is essential to go behind the actual language and evaluate the spirit and intent of that document.

The Outer Space Treaty was negotiated under the

auspices of the United Nations and its Committee on the Peaceful Uses of Outer Space, the Legal Subcommittee, the First Committee, and the General Assembly. As far as the United States is concerned, the official negotiations were set in motion by a proposal offered by President Lyndon B. Johnson on May 7, 1967, that would ensure the Moon and other celestial bodies would be explored for *peaceful purposes* only. "I am convinced," stated the President, "that we should do what we can—not only for our generation, but for future generations—to see to it that serious political conflicts do not arise as a result of space activities." Not only was President Johnson concerned that space be explored for peaceful purposes *only*, but also that space likely would be used for warfare if a firm prohibition with the heaviest moral sanction was not included in any treaty encompassing this principle. The scientific and material benefits to mankind of a new and promising frontier he clearly viewed as secondary objectives.

In a May 9, 1966, letter to Kurt Waldheim, then chairman of the UN Committee on the Peaceful Uses of Outer Space, requesting an early convening of the legal subcommittee of the Committee on Outer Space to consider a United States draft space treaty, UN Ambassador Arthur J. Goldberg emphasized that UN "Resolution 1721, of December 20, 1961, set forth the essential legal principles applicable to outer space in an enlightened fashion that *has no precedent in any previous age of exploration.*" [Italics added.] Again, it was clear that the United States did not wish to give the appearance that it considered this simply "treaty business as usual."

In a May 30, 1966, letter to the Secretary General from Soviet Ambassador to the UN, N. Fedorenko, a statement by USSR Minister for Foreign Affairs Andrei Gromyko was included which explained the Soviet Union's view on negotiating an outer-space treaty: i.e., "to prohibit the use of the Moon and other celestial bodies for military purposes would be a major step [towards complete disarmament]... and would be calculated to ensure peace on Earth and the security of peoples." The entire tenor of the letter was one of peaceful uses to protect people on Earth—not just in space, but particularly on Earth.

Negotiators hammered out the basic principles of the Outer Space Treaty with great care and difficulty to reflect the noblest intent of the civilized world. The apparent underlying presumption of the United States at the time was that, especially amidst the euphoria of an unfolding new frontier, the "peace image" had not failed as an objective and methodology for establishing reasonably harmonious relations among nations on Earth.

Now the rapidly growing use of "near space" for military purposes presents lawyers and statesmen with a pressing issue: are the United States and the Soviet Union on the verge of massive violations of the Outer Space Treaty, beyond the clear prohibition against weapons of mass destruction? Just because one class of weapons was specifically prohibited based on existing technology in 1967 does not mean that all other weaponry and components of weapons systems would be countenanced by the Treaty.

Most official interpretations and negotiations relating to military activities in space are constrained by complicated policies of governments seeking to secure innumerable economic, ideological, political and military positions. To the professional diplomat and soldier, the basic question remains, "Does military activity in space retard or increase the chances of war on Earth?" Consequently, any objective evaluation of the Outer Space Treaty and its applicability or current effectiveness with respect to the growing military occupation of space must be made outside these military and political influences.

The International Astronautical Federation (IAF) would be an excellent forum for such an evaluation. The International Institute of Space Law, under the aegis of the Federation, cannot analyze effectively the technology, policies, and issues by itself, isolated from other technical committees and associations of the Federation. Serious considerations should therefore be given to devoting a large segment of one of the Federation's annual congresses to analyzing the effectiveness of the Outer Space Treaty regarding the pattern of growth of military activity in space.

If space is to remain some reasonable form of sanctuary from the conflicts of Earth, teeth and resolve should be put into this principal multilateral document to preserve the sanctuary concept. As it now stands, unilateral actions and bilateral negotiations among the superpowers are disfranchising all the other parties to the Outer Space Treaty from effective involvement in resolving the issue of limits to militarization of space.

If the Treaty is determined, say, by the IAF to be inadequate to safeguard the sanctuary concept and the dedication of space to peaceful purposes and the welfare of all peoples, it could pass a strong resolution calling on the United Nations to undertake formulation of an appropriate protocol or amendment to the Treaty. In this way the IAF would help reestablish the Treaty and the United Nations as the proper document and forum for determining what is a peaceful use of outer space, and in doing so would help reestablish informed public opinion as an effective sanction. ■

The Moon Treaty and Private Enterprise

By DELBERT D. SMITH
Attorney at Law

Although nothing in the treaty specifically limits private activities in space, several openings for later restrictions need closing by Senate attachments

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DELBERT D. SMITH, an attorney specializing in international law, particularly satellite communications, serves on the AIAA Legal Task Force. He has written five books—the latest *Space Stations: International Law and Policy*—and many articles for legal periodicals, and edits *Satellite Communications* magazine. He received a Master's degree and J.D. from the Univ. of Wisconsin, Ph.D. in international law from Cambridge Univ., and the Diploma in Public International Law from the Hague Academy of International Law.

The Agreement Governing Activities of States on the Moon and Other Celestial Bodies (Moon Treaty)[1] would be, when adopted and opened for signature by the UN General Assembly, a significant step in the development of international law on outer space. Provisions reaffirm the freedom of exploration and use of outer space and reaffirm recognition of private activities there.

Rights and obligations established or confirmed by the agreement include the rights of nations to collect and remove samples from the Moon for scientific investigation,[2] and to use substances on the Moon and other celestial bodies to support scientific missions,[2] the obligations to safeguard human life,[3] offer shelter to those in distress,[4] offer humanitarian emergency use of lunar facilities to others,[5] periodically notify and give specified information to the UN about lunar missions,[6] and notify the UN in advance of radioactive materials use.[7] The treaty also calls for designating areas of special scientific interest as international scientific preserves.[8] Such measures will help promote space exploration.

Nevertheless, some critics have claimed several articles would inhibit, if not prevent, commercial activities on the Moon and other celestial bodies. As a matter of strict legal interpretation, the agreement would not. The text reaffirms the right of nations to use the Moon, and the term "use" in outer space law has not thus far been interpreted as prohibiting commercial activities. However, the Moon Treaty's anticipation of an international regime to govern the exploitation of the natural resources of the Moon[9] leads some persons to argue that future interpretations and negotiations will inevitably work against the interests of the United States.

Let us look at the background to this issue—conditions surrounding private use and exploitation, and the conceptual basis of "common heritage of mankind"—and the likelihood of a moratorium on exploiting natural resources.

Article XIV recognizes private activities on the Moon and other celestial bodies in these words: "States Parties shall ensure that non-governmental entities under their jurisdiction shall engage in activities on the Moon only under the authority and continuing supervision of the appropriate State Party."

This language closely follows that of Article VI

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of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (1967 Outer Space Treaty),[10] which states: "The activities of non-governmental entities in outer space including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the treaty." Furthermore, it has been generally accepted that the Outer Space Treaty furnished the conceptual basis for subsequent agreements reported out by the UN Committee on the Peaceful Uses of Outer Space (COPUOS). Thus when the committee prepared the Moon Treaty it probably did not intend to modify the basic tenets of the Outer Space Treaty.

The United States further clarified this point by stating its position before the COPUOS as follows: "In regard to the matter of the Moon Treaty's relation to the 1967 Outer Space Treaty, discussion in the Committee resulted in no statements to the effect that the Moon Treaty is intended to weaken in any way the provisions of the 1967 treaty. In this light, and taking into account the last two preambular paragraphs of the Moon Treaty, there was a feeling that a non-derogation provision would be superfluous. Our delegation accepted this view and joined in the consensus on the Moon Treaty *with the understanding that it in no way derogates from or limits the provisions of the 1967 Outer Space Treaty.*"

U.S. Ambassador Petree made the same point before the UN when he said, "The draft Moon Treaty is based to a considerable extent on the 1967 Outer Space Treaty. Indeed, the discussion in the Outer Space Committee confirmed the understanding that *the Moon Treaty in no way derogates from or limits the provisions of the 1967 Outer Space Treaty.*"[12]

Moreover, Article II of the Moon Treaty states, "All activities on the Moon, including its exploration and use, shall be carried out in accordance with international law." Since the 1967 Outer Space Treaty makes up a major part of international law on outer space, to make a change the Moon Treaty would have to contain specific language stating the alteration. Article II's reference to international law has no such qualification.

How unrestricted is the right of use? Article I of the 1967 Outer Space Treaty says, "Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law."

Similarly, Article XI(4) of the Moon Treaty says, "States Parties have the right to exploration and use of the Moon without discrimination of any kind on a basis of equality and in accordance with international law and the terms of this Agreement."

The word "use" should have the same meaning and implications under both treaties. Thus, since commercial activities have been allowed under the terms of the 1967 Outer Space Treaty as a type of "use" of outer space, they should also be permitted under the Moon Treaty.

However, the Moon Treaty attempts to deal specifically with a category of use—exploitation of natural resources—and an issue arises as to whether the treaty circumscribes this particular type of use. Article XI(5) of the treaty says, "States Parties to this agreement hereby undertake to establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the Moon as such exploitation is about to become feasible."[13] Leaving aside the definition of "natural resources," "exploitation" would require definition before one could determine whether, and if so, to what extent, "exploitation" is meant as an exception to the general right. The similar meanings of "use" and "exploitation" present a difficulty. "Use" is to convert to one's service[14] and includes a right to profit from the activity. In U.S. law, "The 'use' of a thing means that one is to enjoy, hold, occupy, *or have some manner of benefit thereof* [emphasis added]."[15] Exploitation means the act or process of making use of by application of industry or other means of turning to account.[16]

The Moon Treaty speaks of exploitation only in connection with exploitation of the natural resources of the Moon and other celestial bodies. Since the difference between "use" and "exploitation" does not depend upon making profits, points of distinction remain to be determined. This may prove difficult, since the two treaties clearly establish the right of use "without discrimination of any kind." At least ten other sections of the Moon Treaty refer to the right of use without any qualification.

Perhaps attaching an understanding to the agreement clarifying the U.S. interpretation of the right of use of outer space would solve the matter. This could be done during consideration of the treaty by the U.S. Senate. Such an understanding or reservation would help insure that whatever legal regime ultimately comes into being will recognize the ability and right of private enterprise to use and exploit the resources of the universe for the benefit of all mankind. In a broader sense, it would sharpen the legal picture on imposition of a

moratorium and the specific impact of "the common heritage of mankind" as well.

Although the word "moratorium" does not appear in the Moon Treaty, a dispute has arisen over whether providing for setting up an international regime implies a hold on exploitation. In a statement before the COPUOS, the U.S. representative pointed out, "The draft agreement...as part of the compromises made by many delegations, *places no moratorium upon the exploitation of the natural resources of celestial bodies, pending the establishment of an international regime* [emphasis added]. This permits orderly attempts to establish that such exploitation is in fact feasible and practicable, by making possible experimental beginnings and, then, pilot operations, a process by which we believe we can learn if it will be practicable and feasible to exploit the natural resources of such celestial bodies."[18]

During the 1979 Session of the Legal Subcommittee of the COPUOS, a language change introduced would have created a moratorium. The change was not made. Ambassador Petree reiterated the above position that there is no moratorium, and also noted that the purposes specified in paragraph 7 of Article XI establish a framework and incentives for such exploitation. "By setting forth now the purposes governing exploitation of natural resources, uncertainty is decreased and both states and private entities may now find it possible to engage in the arduous and expensive efforts necessary if exploitation of the natural resources of celestial bodies is ever to become a reality,"[19] he said.

Article XI(5) states that the parties "hereby undertake to establish" a regime. It states no requirement for a regime before exploitation. Nor does Article XI(5) set a specific deadline for establishing the regime. Rather it refers to the time when "exploitation is about to become feasible." In addition, Article XI(5) references Article XVIII which states that at any time after the agreement has been in force for five years, the Secretary-General of the UN at the request of one-third of the states parties to the agreement and with the concurrence of the majority of the states parties, may convene both a conference to review the treaty generally and a specific conference to consider implementing the provisions of Article XI, para. 5.

When and if negotiations for a regime begin, Ambassador Petree has stated, "My government will...make a good faith effort to see that such negotiations are successfully concluded. Each of the participants in a regime conference will, of course, have to evaluate any treaty that emerges from the conference in the light of its own national interests. For the United States, this would require a conclusion that the treaty is balanced and reasonable and would then, as a constitutional matter, require submission to the Senate for its advice and consent, just as we have sought and obtained advice and consent to United States ratification of the four outer space treaties now in force."[20]

The lack of a provision in the Moon Treaty similar to one introduced by India in 1973—"Exploitation of the resources of the Moon and other celestial bodies and their subsoil shall not be done except in accordance with the international regime to be established"—also indicates the absence of a moratorium.[21] The White House has expressed a U.S. policy to "encourage domestic commercial exploitation of space capabilities and systems for economic benefits."[22] And the U.S. can be expected to keep up negotiating pressure in support of that policy. Thus a de facto moratorium appears unlikely. If uncertainty remains, the understanding proposed above should include a clarification.

Predictions that an international regime would be unfriendly toward the private sector's developing outer space stem from the history of the Law of the Sea negotiations and the significance some nations place on the phrase "common heritage of mankind."

In Article XI (1), the Moon Treaty says, "The Moon and its natural resources are the common heritage of mankind, which finds its expression in the provisions of this Agreement and in particular in paragraph 5 of this Article." "Common heritage of mankind" has come under discussion for the past decade, but no universally acknowledged definition of the phrase or agreement as to whether it represents a valid "principle" of international law has resulted. Thus, to avoid the lack of agreement over what the phrase means, drafters of the Moon Treaty linked it to the provisions of the agreement and to a yet to be established international regime, the purposes of which are set forth in Article XI(7). Therefore, any meaning assigned to the phrase in other international law does not automatically apply to the Moon Treaty. Any attempt to expand "common heritage" beyond an ideal of providing nations with nondiscriminatory access to the resources of outer space will probably necessitate an intensive review by the United States.

Article XI(7)'s purposes of a future international regime recognizes that "equitable sharing...in the benefits derived from ...[natural] resources" must give special consideration to "the efforts of those

countries which have contributed either directly or indirectly to the exploration of the Moon" as well as to "the interests and needs of the developing countries." Such international cooperation exists today in the practical applications of outer space, particularly in Intelsat and Inmarsat, where "those states who have expended large resources, either public or private, to develop space systems to exploit these applications have equitably shared the benefits with the international community."[23]

If a question remains on the interpretation of the "common heritage of mankind" or "equitable sharing," once again an understanding or reservation would seem the best course.

The world is proceeding toward the codification of the international law on outer space. In the course of codification the U.S. has found itself dealing with controversial concepts. One of the broader questions it must face is how to deal with specific provisions of an agreement without isolating itself and hampering U.S. private participation in international space system development and operations in communications, remote sensing, and related areas. Understandings and, if necessary, reservations to specific articles in agreements may be a desirable first step.

Since the U. S. introduced the "common heritage" language in 1972, it should expend effort on determining whether or not the concept requires supporting private involvement and operations in outer space. Issues over "sharing," "equity," "international regimes," and "common heritage" will probably arise many more times in the Eighties. The U.S. should begin developing arguments to support its interpretations of these concepts at a future international regime conference or during deliberations on future international treaties. At a minimum it should bring together the various U.S. interests, organizations, and groups involved in outer space to agree upon principles.

The practical implications of international law of outer space are being realized when it is still possible not only to balance various interests, but to create a conceptual basis to benefit both the U.S. and all mankind.

References

1. The UN Committee on the Peaceful Uses of Outer Space has submitted the draft Moon Treaty to the UN General Assembly for final adoption. "Report of the Committee on the Peaceful Uses of Outer Space," *Official Records of the General Assembly, Thirty-Fourth Session, Supplement No. 20* (A/34/20), p. 12.

2. Article VI(2) of the draft Agreement Governing Activities of States on the Moon and Other Celestial Bodies. The text of the Moon Treaty is contained in the "Report of the Committee on the Peaceful Uses of Outer Space," *Official Records of General Assembly, Thirty-Fourth Session, Supplement No. 20* (A/34/20), Annex II.

3. Article X(1), Ref. 2.

4. Article X(2), Ref. 2.

5. Article XII(2), Ref. 2.

6. Notification and specified information is required upon completion of a mission or every 30 days for a mission of long duration. Article V, Ref. 2.

7. Article VII(2), Ref. 2.

8. Article VII(3), Ref. 2.

9. Article XI(5), Ref. 2.

10. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and other Celestial Bodies, Jan 27, 1967, 18 U.S.T. 2410, T.I.A.S. 634, 510 U.N.T.S. 205, entered into force for U.S., Oct 10, 1967.

11. UN Doc. A/AC.105/PV.203.

12. Statement by Ambassador Richard W. Petree, U.S. Deputy Representative to the UN Security Council, in the UN General Assembly Special Political Committee on the Report of the UN Outer Space Committee and the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, Nov 1, 1979, p. 5.

13. A general reference appears in the Preamble to the Moon Treaty which points out that the states parties to the agreement: *"Bearing in mind* the benefits which may be derived from the exploitation of the natural resources of the Moon and other celestial bodies..."

14. Hopkins vs. Howard's Ex'x, 226 Ky. 685, 99 S.W. 2d 810, 812, cited in *Black's Law Dictionary*, Revised Fourth Edition, 1968, p. 1710. "To make use of, to convert to one's service, to avail one's self of, to employ."

15. Bryson vs. Hicks, 78 Ind. App. 111, 134 N.E. 874, 875 cited in Ref. 14, p. 1710.

16. State Finance Co. vs. Hamacher, 17 P.2d 610, 613 cited in Ref. 14, p. 689.

17. References to use of the Moon are in the preamble, and Articles II, III(1), III(2), IV(1), V(1), VII(1), VIII(1), XI(4), and XV(1). In each instance the reference to "use" is not qualified, although the reference to "use" in Art. III restricts use in terms of peaceful purposes. Moon Treaty, Ref. 2.

18. UN Doc. A/AC.105/PV.203, July 16, 1979.

19. R. W. Petree, Ref. 12, p. 7. The purposes listed in Article XI(7) include the orderly and safe development of the natural resources of the Moon; the rational management of those resources; the expansion of opportunities in the use of those resources, and an equitable sharing by all states parties in the benefits derived from those resources, whereby the interests and needs of the developing countries which have contributed either directly or indirectly to the exploration of the Moon shall be given special consideration.

20. R. W. Petree, Ref. 2, p. 6.

21. UN Doc. A/AC.105/102, Para. 21, Mar 27, 1973.

22. Press release, Office of the White House Press Secretary, June 19, 1979.

23. R. W. Petree, Ref. 12, p. 7. ■

III. SPACE EXPLORATION AND DEVELOPMENT: SCIENTIFIC AND COMMERCIAL

A. Policy and Economics

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U.S.-European Cooperation in Space Science: A 25-Year Perspective

John M. Logsdon

Summary. In the past 25 years, the National Aeronautics and Space Administration has engaged in a range of cooperative activities in space with other countries and international organizations, most of the scientific interactions being with Europe. The character of U.S.-European cooperation in space science is changing as a result of the increased maturity and level of space capability which Europe is bringing to the partnership; the consequent addition of a competitive dimension to the relationship; the increasing cost of space science missions; and the relative scarcity of funds available for space science. A number of issues flow from the current situation, but in general the outlook is for continued productive cooperation between the United States and Europe in space science.

In the 25 years that the United States has had a government space program, international cooperation has been one of its major themes. An objective of the National Aeronautics and Space Act of 1958, which was the charter for the civilian space program and which established the National Aeronautics and Space Administration (NASA), was "cooperation by the United States with other nations and groups of nations in work done pursuant to the Act and in the peaceful applications thereof" (*1*). Armed with this legislative mandate, with presidential and congressional support for a U.S. civilian space program which emphasized openness and scientific objectives, and with already existing patterns of cooperation in space science, NASA has since its inception conducted an active program of international partnership.

In space perhaps more than in most areas of international science, it has been the policies and initiatives of a government agency and its top officials, rather than those of the scientific and technical community, which have established the U.S. attitude toward cooperative undertakings. Although NASA's international programs have involved the Soviet Union, Canada, Japan, and various developing countries, its primary cooperative partner has been Europe—both individual European countries and the various European space organizations which have existed over the past two decades. Table 1 suggests the dominance of U.S.-European interactions in the overall record of NASA's most important cooperative programs.

The U.S.-European partnership in space science has been, on the whole, remarkably successful, in terms of cooperation both between the United States and individual European countries and between the United States and Europe's multilateral space science agencies: the European Space Research Organization (ESRO) and its successor the European Space Agency (ESA). Projects such as Ariel (United States–United Kingdom), Helios (United States–Federal Republic of Germany), Infrared Astronomical Satellite (United States–United Kingdom–Netherlands), International Ultraviolet Explorer (United States–United Kingdom–ESA), and International Sun–Earth Explorer (United States–ESA) are just a few of the major scientific undertakings which have benefited from U.S.-European collaboration. This record of success must be kept in mind in evaluating any past and current stresses in the cooperative relationship.

As the U.S. space program enters its second quarter-century, there are significant changes in U.S.-European cooperation; the major reasons for these changes include: the increased maturity and level of space capability which Europe is bringing to the partnership; the consequent addition of a competitive dimension, both in scientific and economic terms, to the relationship; the increasing cost of space science missions; and the relative scarcity of financial resources available on both sides of the Atlantic for space science.

Last fall saw the first flight of Spacelab, an orbital facility for manned scientific experimentation which was developed by Europe at a cost of approximately $1 billion; Spacelab is designed only for use with the U.S. space shuttle and reflects the intimate character of continuing U.S.-European collaboration. At the same time, Europe has developed its own launch capability in the Ariane series of expendable boosters and is using the autonomous capability not only to launch its own spacecraft but also to compete with the space shuttle for other launch contracts. European countries are also developing satellites for Earth observation and communications and exploring the potential of space manufacturing, with the objective of competing with the United States for economic payoffs from space.

Further scientific cooperation in space between the United States and Europe will occur in this mixed context of collaboration and competition. The state of that cooperation is vigorous, as both the United States and Europe continue the fascinating adventure of exploring the nature of the solar system and the cosmos which is made possible by space technology.

John M. Logsdon is director of the Graduate Program in Science, Technology, and Public Policy, George Washington University, Washington, D.C. 20052.

Origins of U.S. Cooperative Programs

As the late Homer Newell, one of the U.S. pioneers in space science and an early and strong advocate of international cooperation in space, has noted, "with roots in the International Geophysical Year, which had already generated a lively interest in the potential of satellites for scientific research, one might argue that the appearance of an international component in the NASA space science program was inevitable" (*2*). The International Geophysical Year, organized under the sponsorship of the International Council of Scientific Unions (ICSU), was an 18-month (July 1957 to December 1958) effort involving 66 countries, some 60,000 scientists, and the expenditure of hundreds of millions of dollars; both the Soviet Union and the United States agreed in 1955 to launch scientific satellites as part of IGY activities.

There was in place at the very start of the space age, therefore, a nascent international community of scientists who saw space technology as providing exciting opportunities for extending and expanding their investigations. This community was quick to press NASA to keep its program open to international involvement. The pressure was congenial, since one reason the United States had decided to house its major space activities in a separate, civilian government agency was to present to the world an image of peaceful intent and open style: this was in deliberate contrast to Soviet space activities, which were controlled by the military services and conducted with great secrecy. There were those in 1958 who argued that the U.S. space program should be under military control and not opened to international cooperation because "the tools of space research—rockets, radio, radar, guidance, stabilization—were all common to both the military and to science. Even the scientific objectives . . . were of interest and possible value to the military" (*3*, p. 5). Added to this "dual use" character of space technology and some areas of space science was the role of space achievement as an area for superpower political competition, particularly after the United States launched the Apollo program in 1961. Thus scientific activity involving the use of space systems took place in a highly charged political and military environment. By carefully defining the conditions under which cooperative activities would be initiated and carried out, NASA was able to conduct an international program which has been relatively free from distortion for political purposes and from limitations because of military sensitivities. Even so, with respect to space cooperation "a clear duality dogs both the history and the prospects of international partnerships" (*3*, p. 6).

NASA Guidelines and Objectives for International Cooperation

When NASA announced to ICSU's Committee on Space Research (COSPAR) in March 1959 that it would assist COSPAR members in launching scientific experiments and satellites, the agency had already under development a set of policy guidelines for such cooperation. Those guidelines have survived periodic reexamination and remain in force today. They reflect "conservative values" (*3*, p. 32) with respect to the conditions under which cooperation is desirable; shaping those values were both the recognition of the political significance of space activities and the strong personalities of individuals such as Newell and Arnold Frutkin, who directed NASA's international program from the agency's earliest months until the mid-1970's.

The essential features of NASA guidelines are (*4*, p. 18):

- Cooperation is on a project-by-project basis, not on a program or other open-ended arrangement.
- Each project must be of mutual interest and have clear scientific value.
- Technical agreement is necessary before political commitment.
- Each side bears full financial responsibility for its share of the project.
- Each side must have the technical and managerial capabilities to carry out its share of the project; NASA does not provide substantial technical assistance to its partners, and little or no U.S. technology is transferred.
- Scientific results are made publically available.

A key feature of NASA's cooperative efforts is that "while NASA has international programs, it does not fund *an* international program." Rather, "funding for international projects must come out of the NASA program offices," and "for an international approach to a project to be undertaken it must not only contribute to achieving the goals of the interested program office, but it must be considered to be among the best approaches to achieving these goals (*5*, p. 68). This emphasis on technical soundness and scientific merit has been a consistent feature of the U.S.-European cooperation over the past 25 years, whatever other objectives are sought through such cooperation. As one perceptive analysis notes, "although NASA recognizes possible political benefits from achieving utilitarian goals, NASA's cooperative programs are justified almost entirely on technical and scientific grounds, both within and outside" the agency (*4*, p. 49). The objectives of NASA's international programs can be grouped as shown in Table 2.

While the priority given to these various objectives has varied with time and mission opportunity, at the core has been a policy that permitted this country's closest allies to become involved in the U.S. space effort. Indeed, some have criticized NASA for making possible such participation, at minimal cost, in an effort paid for almost entirely by U.S. taxpayers: "benefit, know how and opportunity were shared to an extent that was entirely unprecedented where an advanced technology was involved, particularly one with such strong national security implications" (*6*, p. 74).

Evolution of U.S.-European Cooperation in Space Science

During the "golden age" of the U.S. space program, from the beginning of the Apollo buildup in 1961 through its peak in the 1965–1966 period, NASA's international activities grew rapidly along with the rest of the agency's efforts. Before the first Apollo 11 moon landing in July 1969, nine European spacecraft had been launched by the United States, and substantial momentum had built behind European involvement with the United States in space experimentation. This momentum has carried through to the current day, but, as one top-level participant has commented, "when resources abound and opportunities are plentiful, a cooperative attitude abounds. . . . When the resources and opportunities shrink, . . . altruism takes a back seat and . . . scientists take a more selfish view of cooperation" (*7*, p. 38).

Several factors have influenced the evolution of U.S.-European space cooperation in the period since 1970. In no particular order of importance, they are:

- Shrinkage in the NASA budget overall in the post-Apollo era. The space science budget came under particular pressure as the share of overall resources going to shuttle development increased. This meant fewer science missions and more competition among U.S. scientists to get their experiments on the missions which were approved.
- A broadening of NASA's interna-

tional program to encourage European participation, not only in science missions, but also in developing large space systems including manned space flight elements.

- Evolution of the 11-member European Space Agency, founded in 1975, into an effective entity. ESA has carried out a successful science program of its own and has managed several space applications projects and two major hardware development programs, Spacelab and Ariane. The national space programs of France, Germany, Italy, the Netherlands, and the United Kingdom, with differing emphasis, are also vigorous.
- More recently, growing concern in the United States that cooperative undertakings in space, including space science, could serve as vehicles for unwanted transfer of militarily or economically sensitive U.S. technology to other countries.

While Europe has continued to cooperate with the United States, it has also become a formidable competitor in various categories of space applications and in some fields of space science. Europe is now a very capable actor in space, and it could become more difficult for the United States to develop cooperative projects on its preferred terms. While the United States remains the partner of choice for ESA and individual European countries, existing and potential cooperation with the Soviet Union and Japan provides an alternative. There is now the possibility of a global division of labor and cost in space science, and this makes the task of planning and getting agreement for major space science projects both challenging and full of opportunities.

There has been an undercurrent of ambivalence among U.S. space scientists and NASA managers about European involvement in NASA missions, whatever the stated policy. For one thing, "always the U.S. side was slightly constrained by fear that foreign collaborators . . . might not fulfill their commitments." This concern had diminished over time; "in the few cases where serious delays occurred, as in the Solar Polar project, it was more often the United States that was responsible. . . . Had NASA personnel not been susceptible to the then universal belief that other nations necessarily lagged behind the United States in technological capability, the policy of collaboration in space matters could almost certainly have been more rewarding" (*6*, p. 71). For another, when foreign experiments have been selected by NASA, some U.S. scientists have raised the question of whether the foreign experiment was selected over a competing U.S. experiment on the basis of merit or whether it was selected because it would be provided to NASA free of charge (*7*, pp. 38–39). Another reservation with respect to foreign participation has been that "by selecting a high-technology experiment, the United States encourages development of the industrial base in the foreign country which will contribute to a decreased United States competitive position in world trade" (*7*, p. 39). Yet another concern is that management of a U.S. space science project is greatly complicated by the need to integrate the experiments or other contributions from a foreign partner.

Table 1. Patterns of international cooperation, 1958 to 1983, including past and currently approved cooperative projects (*17*).

Participant	Cooperative spacecraft projects	Experiments with foreign principal investigators
Total	38	73
Total, Europe	33	52
European Space Agency	8	1
France	2	17
Federal Republic of Germany	7	11
United Kingdom	7	18
Italy	6	1
Netherlands	2	3
Spain	1	
Belgium		1

While growing European capability has muted concern about the first of these factors, it has also created healthy competition among all space scientists for access to orbit and beyond for their experiments. European scientists have always been able to propose experiments on U.S. missions, but U.S. scientists are only now gaining a reciprocal opportunity to serve as principal investigators for experiments on ESA missions.

A major attempt to engage Europe with NASA's technology development efforts took place in the 1969–1973 period, as NASA itself sought to gain presidential and congressional approval of an ambitious post-Apollo program of manned space flight. The negotiations on European participation in the program were much more political in character than prior (and subsequent) negotiations on cooperative undertakings in space science. This post-Apollo experience, perhaps justifiably, has left a lingering "bad taste" in Europe. NASA's objective was "to stimulate Europeans to rethink their present limited space objectives, to help them avoid wasting resources on obsolescent developments [a reference to European plans to develop an independent launch capability], and eventually to establish more consider-

Table 2. Objectives of NASA's international programs.

Scientific/technical

"Increasing brainpower working on significant problems and expanding scientific horizons by making space an attractive field for research" (*4*, p. 17).

Shaping the development of foreign space programs to be compatible with the U.S. effort "by offering attractive opportunities to 'do it our way' " (*4*, p. 50).

Through such influence, limiting funds available in other countries for space activities which are competitive or less compatible with U.S. interests.

Obtaining unique or superior experiments from non-U.S. investigators.

Obtaining coordinated or simultaneous observations from multiple investigators.

Increasingly, making available opportunities for U.S. scientists to participate in space science missions of other countries or regions.

Economic

"By sharing leadership for exploring the heavens with other qualified space-faring nations, NASA stretches its own resources and is free to pursue projects which, in the absence of such sharing and cooperation, might not be initiated" (*18*); NASA estimates getting over $2 billion in cost savings and contributions from its cooperative programs over the past 25 years (*5*, p. 69).

"Improving the balance of trade through creating new markets for U.S. aerospace products" (*4*, p. 17).

Political

Creating a positive image of the United States; "the U.S. program of cooperation in space reaches a scientific, technical, and official elite in the struggle for minds" (*3*, p. 73).

Encouraging European unity; the U.S. space program "lends itself admirably to cooperation with multilateral institutions in Europe" (*3*, p. 78).

Reinforcing the image of U.S. openness in contrast to the secrecy of the Soviet space program; "when NASA was organized . . . the keystone of Government space policy was to give dramatic substance to the claim of openness—and, at the same time, to seek credibility for the nation's assertion that it entered space for peaceful, scientific purposes. This was done . . . most importantly, by inviting foreign scientists to participate extensively and substantively in space projects themselves" (*6*, p. 70).

Using space technology as a tool of diplomacy to serve broader foreign policy objectives.

able prospects for future international collaboration on major space projects" (*8*).

A basic problem in this case was that NASA could not deliver what it was promoting in Europe. NASA's post-Apollo ambitions included a space station and a fully reusable space shuttle, and the agency continued to solicit European involvement in these programs even when their approval by the President was very uncertain. Indeed, within the United States NASA tried to use the prospect of collaboration with Europe as a selling point for approval of these programs. When only the space shuttle remained as a potential program, NASA encouraged Europe to consider developing both components of the shuttle orbiter and a separate major project, a reusable orbital transfer vehicle called a space tug. However, NASA was forced to withdraw these offers at the last minute when the Air Force, whose support was needed for shuttle approval, objected to European development of essential elements of the Space Transportation System; when concerns regarding excessive transfer of propulsion technology were raised; and when some in NASA became concerned about the safety implications of placing a cryogenically fueled tug in the shuttle payload bay. Finally, NASA offered Europe the comparatively simple and less expensive task of developing a "research and applications module" to fit into the shuttle payload bay; this is what became the Spacelab project.

By this time, Europeans were rather skeptical about NASA overtures, but they (particularly Germany) had also become so eager to embark on manned flight activities that they agreed to develop the Spacelab system under what in hindsight have been seen as unfavorable terms; the first set of flight hardware, developed with European funds, was to be transferred to NASA, and after an initial joint NASA-ESA mission which included flying a European payload specialist, Europe was to pay for future shuttle-Spacelab flights. NASA agreed to buy a second set of flight hardware from Europe, but "a significant segment of the European space community believes that the United States is getting the lion's share of the benefits from Spacelab" (*9*).

European space officials have described themselves as "stupid" in accepting the U.S. terms for involvement in its post-Apollo program and believe that such acceptance stemmed from lack of confidence in European capabilities and from a belief that only through cooperation with the United States could those capabilities be improved. Now, having brought both Spacelab and Ariane to success, Europe has much more confidence in its ability to chart its own future in space and it will be a more demanding participant in negotiations with the United States over cooperative ventures (*10*).

European confidence in the United States as a cooperative partner was shaken in the spring of 1981 when the United States announced, without prior consultation with its European partners, that it was canceling a U.S. spacecraft which was part of a two-spacecraft International Solar Polar Mission (ISPM). This withdrawal caused vigorous protests not only from European space officials but also from representatives of foreign ministries (*11*). In this case, "NASA's success in international participation became a political liability" (*5*, p. 69); NASA was forced to reduce funding in a major space science mission, and all three existing large missions—the Space Telescope, the Galileo mission to Jupiter, and the Solar Polar mission—had major European involvement.

There is general agreement that the ISPM affair was handled clumsily, and both the United States and Europe have moved beyond it, although European officials are not beyond using U.S. guilt over the incident as a bargaining chip in U.S.-European negotiations on future collaboration.

In summary, U.S.-European cooperation in space has become a much more complex enterprise in the last 10 years as both U.S. and European space efforts matured. While the balance sheet in that enterprise remains strongly on the positive side for all participants, competition and conflict have joined collaboration as hallmarks.

Current Issues in U.S.-European Cooperation

The major U.S. science missions now approaching launch, the Space Telescope and the Galileo spacecraft to Jupiter, have major participation by Europeans, and it is anticipated that there will be continuing cooperation as the United States and Europe begin new missions. The following are some of the issues which will influence the development of that cooperation.

Closer coordination and collaboration in planning and conducting space science efforts. The task of maximizing the scientific payoff from the resources available in the United States and Europe (and other countries) for space research is perhaps the key continuing issue in this area. The United States, ESA, and various European countries are all fully capable of undertaking major space science missions on their own, but with limited funds available on both sides of the Atlantic, there is a need to develop a coordinated approach to space science which recognizes the benefits of cooperation and the realities of competition. To date, attempts to do this have primarily involved negotiations from government agency to government agency. There are regularly scheduled meetings between the heads of NASA and ESA and between the space science directors of the two agencies.

The most recent NASA-ESA space science planning meeting took place in June 1983, and the issues addressed exemplify the problems and potential of a coordinated approach to future space science undertakings (*12*). Three areas of cooperation were discussed: (i) infrared astronomy, (ii) solar terrestrial research, and (iii) planetary exploration. In the first of these areas, in essence the United States and ESA "agreed to disagree." The issue under discussion was the next step beyond the highly successful U.S.-Dutch-British Infrared Astronomical Satellite (IRAS) launched in early 1983. Both the United States and ESA have developed future mission concepts, and the two approaches are not compatible. The meeting noted both "NASA's strong interest in collaborating to develop a single major international infrared space telescope facility" (presumably based on the U.S. mission concept) and "the firm commitment of ESA" to its mission. Recognizing that "the difference in orbit and launch vehicle restrict any major hardware collaboration," NASA and ESA agreed to coordinate the planning for the separate missions to maximize their complementarity and overall scientific return, but also for the time being abandoned hope of a joint mission.

By contrast, an examination of the large number of missions under study in the United States, Europe, and Japan in the area of solar terrestrial physics identified "considerable merit in considering a joint . . . mission"; NASA and ESA established a working group, which will also include Japan, to "loc': for joint missions which can satisfy the main scientific requirements in a cost-effective way." Similarly, NASA and ESA agreed in the planetary exploration area "to identify mutually beneficial opportunities for cooperative missions." In particular, the two agencies are to study a joint

Saturn-Titan probe mission for a 1992 launch. Planetary exploration is one of the areas of international scientific cooperation agreed on at the Versailles-Williamsburg series of summit meetings and is also the focus of attention of a working group of the National Academy of Sciences and the European Science Foundation. A cooperative Saturn-Titan mission, if feasible, would thus be politically as well as technically significant.

Another example of the benefits of a coordinated approach to mission planning in a particular area of science is found in the U.S.-German interaction in x-ray astronomy. A large community of investigators has developed to use the data produced by NASA's High Energy Astronomical Observatory. However, there would be a data gap of a number of years before the next mission in x-ray astronomy were it not for the existence of a German project called *Roentgensatellit* (ROSAT). The United States and Germany in 1982 signed a Memorandum of Understanding for close collaboration in this mission, thus ensuring continuity in the field for U.S. as well as European scientists (*13*).

There is a growing need for the United States, Europe, Japan, Canada, and perhaps eventually the Soviet Union and other space-capable states to work together in space science, from the early stages of developing a mission concept to the joint funding and conduct of various missions. Because of its dominant position in space activities in the free world, the United States in the past has been largely able to shape such collaboration to its own objectives. This situation no longer obtains, and there could be a difficult period of adjustment for this country as the new reality of partnership among relative equals becomes the standard pattern. It may prove advantageous for NASA to engage the U.S. scientific community more intimately in developing its international programs; this could minimize international misunderstandings and perhaps blunt nonproductive and expensive competition. In space science, as in many other areas, the United States is adjusting to the recognition that it cannot be first in everything.

Involvement of non-NASA scientists in shaping international cooperation. "At present, ideas for joint international endeavors are primarily developed at formal meetings between representatives of the various governments. . . . There is a need for a more effective forum which would enable space scientists and managers to exchange ideas informally (*14*). While NASA plans its science programs in close consultation with the external science community, including the Space Science Board (SSB) of the National Academy of Sciences, there is little tradition of SSB involvement in international space science matters. The National Academy is the U.S. member in COSPAR, but that forum has little apparent influence on national space programs. Of course, informal interaction among space scientists in various countries interested in similar scientific problems is a major source of project proposals in both the United States and Europe.

The nearest European equivalent to the SSB is the Space Science Committee (SSC) of the European Science Foundation. This committee has a small budget and has not developed close ties with the European Space Agency. Nevertheless, the SSB and SSC held joint workshops in 1976, 1978, and 1983, and some consideration is being given to establishing standing SSB-SSC working groups in selected areas of space science.

In a separate development, at the initiative of the heads of the European Science Foundation and the National Academy of Sciences, a joint SSB-SSC working group on planetary exploration has been established. The U.S. side of this group is composed mainly of individual scientists who are closely related to NASA's Solar System Exploration Committee.

All these developments may represent initial steps in opening up the process of planning U.S.-European cooperation in space science to more structured participation of nongovernment scientists. As scientific competition among those working in space becomes increasingly international, such involvement may be required to reach agreement on how to coordinate or cooperate in research on major scientific problems.

Access for U.S. experimenters to European science missions. If Europe is to approach parity in influencing the direction of progress in various areas of space science, there must also be a mutuality of opportunity for U.S. and European scientists to participate in the resulting activities. NASA has from the start opened its "Announcements of Opportunity" to all free-world scientists, but ESA and individual European countries have limited access to their scientific missions to European scientists, at least as principal investigators. This policy may have been defensible as a means of developing a European space science community, but NASA is now demanding reciprocity of access. Germany has already indicated its willingness to comply. For the ESA mission to Halley's comet, *Giotto*, nine of the ten experiments have U.S. coinvestigators (a total of 33 individuals); ESA has agreed in principle to open up its future missions to U.S. principal investigators, and a NASA-ESA committee is now studying how best to implement that agreement.

Increasing militarization of space activities. Space technology had its origin in military missile and satellite programs, and there has been continuing attention to ensuring that the international programs of NASA do not provide access to militarily sensitive technology. Now the major U.S. launch system is the space shuttle, which is a national capability used for NASA, Department of Defense, and non-U.S. missions. In this context, "classified operations will be a necessity and are bound to lead to a more restrictive atmosphere, less conducive to international cooperation; tending to lead in the same direction . . . are developments in detector technology and in active atmospheric-magnetospheric experimentation" (*7*, p. 40). It is well beyond the scope of this article to discuss the increasing military interest in various uses of space technology, but if the Department of Defense budget for space, which is already larger than NASA's, continues to grow, there is likely to be an impact on international space science. One possibility is increased international cooperation on defense applications of space among the United States and its North Atlantic Treaty Organization allies. Other areas of scientific collaboration have been able to coexist with military interest in the same scientific area and its underpinning technologies, and this duality has been present in space from the beginning; nevertheless, the changing context of space activity must be of concern to those interested in promoting open international cooperation in space science. In particular, several members of ESA are neutral states which could object to being involved in cooperative activites with the United States which had any hint of military overtones.

Impact of space shuttle on scientific cooperation. The space shuttle is an extremely capable launch system and short-term orbital platform. It offers scientists an environment much different from any previously available in which to design and operate their experiments; there is even the chance to accompany them into orbit. Europe has recognized the shuttle's potential and is designing systems for its own and cooperative space activities which can only be used with the shuttle. These include Spacelab and an ESA-developed unmanned free-flying platform called *Eureca*, scheduled

for a 1987 launch. As the shuttle, Spacelab, and other systems become more familiar to scientists, there will emerge innovative ways to take advantage of these new capabilities.

However, U.S. and European scientists will also share a common problem as they plan their missions for the Space Transportation System; because it is a manned system, the requirements for qualifying payloads to go aboard it and for supporting those payloads with documentation are both demanding and expensive, especially in comparison to similar requirements for unmanned launches. When European scientists began to plan for the use of Spacelab, for example, they "were really shocked by the requirements for testing and documentation and the associated cost of those requirements" (*9*). Europe is continuing to find it difficult to afford to use elements of the Spacelab system for its experiments; the result is that "continuous use of Spacelab by those who built and financed it is not likely" (*15*). Whether the shuttle will prove to be a crucial asset for those planning future science missions or a source of costs which limit the number of missions that are affordable is yet to be determined, but the impact of the shuttle is of crucial importance to U.S. and European space scientists alike.

Possible U.S.-European collaboration on space station. The U.S.-European interaction over a European role in NASA's major post-Apollo programs has colored the whole of transatlantic cooperation in space over the past decade. Similarly, outcome of the just-beginning interactions over European participation in NASA's proposed space station program may affect the overall prospects for European-U.S. collaboration over the next decade or more. This impact could have several dimensions. (First, of course, NASA must get approval to begin such a program.) Europe has been following NASA's planning for the space station quite closely and has carried out parallel studies of options for European participation; in essence, NASA and ESA are already traveling together down a path that could lead to a major European role in an evolving station effort. This early and close involvement is quite different from what occurred in the post-Apollo period and signifies how close the U.S. and European outlooks on space have become.

If, after this start, something intervened to make large-scale collaboration on station development impossible, there would certainly be a ripple effect on other areas of cooperation. On the other hand, a joint decision to move ahead with significant collaboration on the space station would cement the increasingly intimate relationship between the planning and conduct of U.S. and European space activities. While there would still be economic competition and rivalry over scientific achievement, they would occur within a broader cooperative framework.

One rationale for developing a space station and associated infrastructure is to create a research facility in Earth orbit. Just as the existence of the space shuttle and Spacelab will define the conditions for most space science missions in the coming decade, so would the availability of permanent orbital facilities condition the conduct of space science in the 1990's. Thus, it is important to the space science community that any space station which is developed be a congenial base for its experiments, and pressure from U.S. and European space scientists will be important in ensuring that that is the case.

Conclusion

Kenneth Pedersen, NASA Director of International Affairs, has commented that "international space cooperation is not a charitable enterprise; countries cooperate because they judge it in their interest to do so" (*16*). This observation can be extended to the level of individual space scientists; in the 25 years since scientific experiments in outer space became feasible, U.S. and European scientists have found it increasingly in their individual and mutual interest to carry out much of their activity on a cooperative basis. NASA's policies have encouraged and facilitated such cooperation; one result has been the nurturing of a vigorous space science community in Europe as well as the United States.

That community today recognizes the high stakes involved in maintaining effective communication and cooperation across national borders; this appears the only way for space science to thrive. The simple missions have already been flown, resources for space science are scarce, and a coordinated approach to the planning, funding, and conduct of complex science missions makes eminent sense. New ways may be needed to allow space scientists to join with the government organizations through which they function in a collaborative enterprise of cosmic discovery, but in general the outlook for international space science in the coming decades is one of great promise and excitement.

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IS THERE PUBLIC SUPPORT FOR SPACE EXPLORATION ?

By Jon D. Miller

In almost every discussion of the space program, conversation eventually turns to the question of whether there is a sufficient level of public support to continue and expand the nation's commitment of public funds for this purpose. This worry is expressed in private conversations with the administrators and engineers at the National Aeronautics and Space Administration (NASA) and by the members and staff of Congress.

On the surface, there is reason both for concern and for some hope. Over the last decade the percentage of

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JON D. MILLER is director of the Public Opinion Laboratory and associate professor of political science at Northern Illinois University, DeKalb, Illinois. He is the author of *Citizenship in an Age of Science* (Pergamon Press, 1980) and *The American People and Science Policy* (Pergamon Press, 1983), and is continuing his work in the study of the formation of political attitudes and the translation of attitudes into the policy formulation process.

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Americans who think that the government is spending too much on the space program has declined, and a majority now report that space spending is either "about right" or even too low. That is the good news. At the same time, a substantial number of Americans have some reservations about large public expenditures for space and other "distant" programs when important domestic needs are unmet. The old tension is still there.

Although the aggregate trends appear to be edging toward increased support for space exploration, many engineering and political leaders worry about the stability of this support. More specifically, as the costs of the development of a space station become better understood by the public, some leaders worry that the public will decide the costs of space exploration exceed the advantages and, subsequently, that the recent gains in aggregate public support will erode quickly.

I have been monitoring public attitudes toward space exploration over the last several years, and I believe that the source of much of this concern is a misunderstanding of the nature of public interest in, knowledge about, and attitudes toward specialized issues like the space program. Viewed in the context of the actual channels of public participation in such areas as space exploration or spending, I think that the evidence points to a strong core of support for NASA's programs, the opportunity for expanding the present activist group, and the absence of any organized opposition to the U.S. space program. The following discussion will outline these arguments in more detail.

A Question of Salience

The basic problem in studying public attitudes toward the space program is that space exploration is not a salient topic to most Americans. Despite the successes of the Apollo program and the current achievements of the shuttle program, only one in three Americans expresses a high level of interest in space activities. For those of us who are interested in space exploration, this level of interest may seem implausible, but it simply reflects the complexity of modern life.

For any given person the range of possible interests is vast. One of the characteristics of modern society is that the volume of information is overwhelming and no single individual can become or remain knowledgeable about more than a relatively narrow range of topics. In marked contrast to our frontier ancestors who waited eagerly for old newspapers from the East, the plight of the modern citizen is to sample selectively from the enormous volume of information available. Inevitably,

a specialization process emerges.

"Issue attentiveness" refers to a specialization process in which the following occur:

- individuals tend to focus their attention on a relatively small number of public affairs issues;
- they stay informed about only that set of issues; and
- any active citizenship role the individual may take is only in regard to those issues.

The concept of issue attentiveness was first described by Gabriel Almond in 1950 in discussing the public's understanding of and participation in foreign policy matters in the United States.[1] I have used the concept to study attitude development among young adults,[2] and to analyze adult participation in the formulation of science policy in the United States.[3] While the process of issue specialization is described in greater detail in other publications, it may be useful to review the basic rationale and impact of the process prior to using it as a means for understanding the basis of public attitudes toward space exploration.

The need for specialization springs from a combination of two basic forces. First, citizens in the latter part of the twentieth century are faced with a large number of competing demands for their time, of which they have only a fixed amount. There is ample evidence of the growth of time pressures over the last several decades and no evidence of a reversal of that trend.

Faced with a large number of competing and attractive demands on time, fewer adults decide to devote a significant share of it to public affairs. This has been observed, for example, in the steady decline in public participation in the political system over the last four decades. Even presidential elections, which command the highest levels of public concern and participation, attract barely half of the eligible adults in the United States.

Second, during the last forty years, the information threshold for many political issues has been increasing. An individual must now have more specialized information to be knowledgeable about almost any given public policy issue. Issues involving space exploration fall into this category, as do most of the areas of concern on the national political agenda.

The combined effect of these two forces has been the narrowing of the political horizons of most American adults to only a small number of public affairs issues. It is important to note that this is not the same process as "single issue" politics, which revolves totally around one strongly felt position; rather, it is a rational and gradual narrowing of the number of topics on which an individual can hope to remain adequately informed.

A Stratified Model

How, then, does this specialization process affect the formulation of public policy? In his original work, Almond outlined a pyramidal structure to illustrate the types of public participation in the policy formulation process that are likely to occur under conditions of issue specialization. In this stratified model, the policy makers are at the pinnacle of the system and represent those persons who have the power to make binding decisions on a given policy matter. This group would include a mix of executive, legislative, and judicial officers. In the case of space exploration, the officers would be primarily at the federal level.

The second level of the system consists of non-governmental policy leaders. In the case of space exploration, this group would include leading scientists and engineers active in aeronautics and astronautics, leaders of major corporations active in the area, disciplinary and professional societies relevant to space exploration, and, more recently, voluntary associations of interested and informed citizens like the Planetary Society and the National Space Institute. This leadership group interacts regularly with policy makers, and there is some movement of non-governmental policy leaders into

Three Studies of Public Attitudes

The analysis reported in this article is based on data from three national surveys. The 1979 national survey of adult attitudes toward science and technology was designed by Jon Miller and Kenneth Prewitt, conducted by the Institute for Survey Research at Temple University, and sponsored by the National Science Foundation (NSF contract C-SRS78-16839). This survey used personal, in-home interviews with 1,635 adults in a national probability sample.[1] The average interview took about 60 minutes, and included items about a wide range of scientific and technical issues.

The 1981 national survey was also designed by Jon Miller and Kenneth Prewitt, was conducted by the Public Opinion Laboratory at Northern Illinois University, and was sponsored by the NSF (grant #103662). This study utilized a national probability sample of households, a sample similar to that in the 1979 study, but employed telephone interviewing techniques. The interviews averaged 30 minutes and covered a wide range of scientific and technical issues and attitudes.

The 1985 survey of adult attitudes was designed by George Gerber, Nancy Signorelli, and Jon Miller. This survey was again conducted by telephone from the Public Opinion Laboratory at Northern Illinois University and was sponsored by the Annenberg School of Communications at the University of Pennsylvania. The interviews averaged about 25 minutes and focused on attitudes toward science and technology, attitudes toward scientists and engineers and the use of prime time television.

J.D.M.

NOTE

1. In a national probability sample, every person with a residence or an operative telephone (depending on whether the interview was conducted in person or by phone, respectively) has an equal chance of being picked for the survey.

Table 1
THE ATTENTIVE PUBLIC FOR SPACE EXPLORATION

	1979 (%)	1981 (%)	1983 (%)
Attentive public for space exploration	8.8	10.2	9.5
Interested in space exploration, but low in information	17.0	15.3	20.0
Interested in science, but not space	28.3	26.2	36.7
Not interested in space or science	46.0	48.2	33.7
N = Total number surveyed =	1,635	3,195	1,631

decision-making posts and of decision makers into the leadership group from time to time.

When there is a high level of concurrence between the decision makers and the leadership group, policy is generally made and there is no wider public participation in the policy process. On some issues, however, there may be a division of views among the policy leadership group itself, or between the policy leaders and the decision makers. In those circumstances, there may be appeals to the attentive public to join in the policy process and to seek to influence policy makers by direct contact and by persuasion.

The attentive public—the third level of the system—is composed of those individuals who are both interested in a given policy area and knowledgeable about that area. To be classified as attentive to a given policy area like space exploration, an individual must express both a high level of interest in space matters and the belief that he or she is reasonably well informed. The analysis that follows will look more closely at the size and composition of this attentive public for space exploration.

While the contacts and processes through which the leadership group mobilizes attentives in various policy areas are only now being studied, it would appear that there is a flow of appeals from leaders to attentives through professional organizations, specialized journals and magazines, and employment-related institutions. Attentives who contact public officials (policy makers) appear to use the traditional avenues of letter writing, telephone calls, and personal visits.

While attentiveness requires both interest and knowledge, another stratum of the public reports a high level of interest in space exploration, but assesses itself to be either moderately or poorly informed about the NASA program. This group will be referred to as the interested public for space exploration. In general terms, the subjectively perceived deficiency of knowledge about space exploration may be expected to make this group less likely to engage in direct contact with policy leaders or decision makers, but they are a pool of interested citizens that might be brought into the attentive category with an improved flow of information about space exploration.

At the bottom of the pyramid is the non-attentive public. For the most part, these individuals display a low level of interest in and knowledge about any given policy areas. However, it is important to understand two major points about this large group.

First, the general population always retains a political veto if they should become sufficiently unhappy about the policies that the decision makers, leaders, and attentives have fostered in any area. The role of the public in ending the wars in Korea and Vietnam illustrates the operation of this veto power. While the non-attentive public does hold political veto power, it rarely exercises it; this segment of the public on any particular issue has no active interest in that issue, and the time, energy, and effort necessary for organizing a successful opposition movement would require the members of this group to become attentive to that cause.

Second, it is important not to equate non-attentiveness to any specific policy area with ignorance or a lack of intellectual activity. We are all non-attentive to a vast number of areas and issues. Many of the persons not attentive to one specific issue area may be interested in and knowledgeable about numerous other issues.

In summary, the process of issue specialization has had a marked impact on the levels and forms of public participation in the formulation of public policy in specialized or technical areas. Unlike some previous theories of a technocratic elite that eliminate all public participation, this conceptualization recognizes that interested and informed citizens—especially in organized groups—can play a role in the formulation of public policy, especially when there are disagreements among the policy leaders or between the policy leadership group and the decision makers. It is not democracy in the tradition of the New England town hall, but if the model is correct it provides for significantly greater public intervention in the policy process than was thought possible only a few years ago. Additionally, it posits the possibility of a public veto on any issue that becomes sufficiently unpopular.

The Public for Space Exploration

How, then, do these ideas apply to the original inquiry about the level of public support for an expanded program of space exploration? If this model is correct, we should be able to define and identify an attentive public for space exploration and to examine its composition and its policy at-

titudes toward the space program.

Utilizing data from a series of national surveys conducted in 1979, 1981, and 1983 (see box on page 27), one can infer that approximately one in ten Americans has both a high level of interest in space exploration and believes himself or herself to be informed about space matters (see Table 1). The size of this attentive public for space exploration has been relatively stable over the last six years, suggesting that peaks of interest in the shuttle and similar activities do not have a substantial impact on this core group. In the context of the earlier discussion about the process of issue specialization, this should not be a surprising result.

The same data suggest that the size of the interested public for space exploration has increased slightly in recent years. The effect of the shuttle program may be reflected in a higher level of interest about space among this segment of the public, but, by their own report, this group does not feel that they understand or know very much about the space program. The 20 percent of the American people in this segment translates into 34 million adults. It would seem apparent that one of the high priorities of the public information program of both NASA and non-governmental groups interested in space should be the focusing of informational activities on this group.

By the logic of the stratified pyramid model, the remaining 70 percent of the American people are not attentive to space exploration—that is, they have little interest in or knowledge about the space program. Because of this lack of interest, and given what we know about the communication of scientific information to the public, it would appear to be very difficult to reach this segment of the population.

Using the same logic, data sets, and methods as applied to space, it is possible to identify that segment of the public that has a high level of interest in scientific and technological matters other than space. While many persons who are interested in science and technology in a broad sense are also attentive to or at least interested in space, the data from the three surveys indicate that about 37 percent of the adult population—about one-half of the uninterested segment—expresses a high level of interest in science or technology, but not in space. A full discussion of the implications of this pattern of interests is beyond the scope of this article, but it is worth noting that this segment of the public might be expected to become more interested in space matters if the activities of the space program were viewed as more scientific in character.

In short, there is a solid core of about 10 percent of the American people—about 17 million citizens—who are attentive to space exploration. This is the segment of the population that we would expect to hold the most positive views of the space program and to be the most willing to engage in direct political activities to further space exploration. An additional 34 million Americans have a high level of interest in the space program but think that they do not have an adequate understanding

Table 2
ATTITUDES TOWARD THE SPACE PROGRAM

	ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Favor continuation of space program (1979)	96	88	67	50
Assessment of cost-benefit balance for space exploration (1981)				
Costs much greater than benefits	10	14	33	NA
Costs slightly greater than benefits	17	17	25	NA
Benefits slightly greater than costs	19	27	23	NA
Benefits much greater than costs	53	42	19	NA
Relative priority for space program (1981)				
Orbital service systems	62	61	75	NA
Deep space probes	38	40	25	NA
Current spending for space is . . . (1983)				
Too low	50	33	12	9
About right	43	47	49	42
Too high	7	20	39	49
Likelihood of people working in space stations in next 25 years (1983)				
Very likely	61	67	55	42
Possible	34	29	31	39
Not likely	6	4	13	16
N (1979) =	143	277	463	752
N (1981) =	327	490	838	1,540
N (1983) =	155	327	599	550

of the program. Almost 50 million more citizens reported a high level of interest in science and technology issues, but not in the space program itself. It would seem that the space program enjoys both a viable core attentive group and has the potential of substantially expanding this group with improved information programs.

Who Is the Attentive Public?

In broad strokes, the attentive public for space exploration is generally under 45 years of age, relatively better educated than most American adults, and twice as likely to be male as female. Approximately 40 percent of the attentive public for space exploration holds at least a baccalaureate. Almost half of the attentive public reported having completed one or more college-level science courses, and 33 percent indicated that they have completed four or more college science courses. Most of the attentives were in upper elementary or high school at the time of Sputnik and experienced the first years of the space race as adolescents or young adults.

In contrast, those citizens categorized as the interested public for space exploration tend to be slightly older and slightly less well educated. Only 30 percent of this group has earned a college degree. Women make up 54 percent of the interested public for space exploration.

At the other end of the spectrum, those persons reporting low levels of interest in space and in science tend to be older, significantly less well educated, and much less likely to have completed a college-level science course. Approximately three out of five persons in this segment of the public are women.

Attentive Public's Policy Views

Having identified a segment of the public that has a high level of interest in space exploration and believes itself to be adequately informed on the issues, it is appropriate to ask, "What are the policy preferences of this attentive public?" If this group were to hold essentially the same views of the space program as the rest of the adult population, there would be little rationale for a special political role for this group.

Data from the same three surveys discussed earlier indicate that the attentive public for space exploration holds significantly more positive views of space exploration than any other segment of the American people. On the basic commitment to continue the space program, for example, the attentive public is virtually unanimous in its support of space exploration, while only half of the uninterested public would favor continuing the program (see Table 2). Similarly, over 70 percent of the attentive public expressed the view in 1981 that the benefits of the space program exceeded its costs.

The attentive and interested publics are markedly more optimistic about the future achievements of the space program than other segments of the public. On a wide range of other nonspace items discussed in the surveys, the attentive public was generally more optimistic about technological achievements than were other segments of the public.

On the critical issue of funding, the commitment of the attentive public to space exploration is most apparent. Half of the attentive public expressed the view in 1983 that space spending is currently too low and only 7 percent of the attentives thought it too high (Table 2). In sharp contrast, only one-third of the interested public thought current spending was too low and only 9 percent of the nonattentive public shared that view. If dollars are the necessary fuel for space exploration, then the attentive public is prepared to support the continuation and expansion of current federal funding for space.

The 1981 survey posed a situation in which limited resources precluded pursuing all objectives of the space program with equal vigor. Each respondent was asked to indicate whether he would prefer to see primary emphasis placed on either deep space probes or orbital service systems. The results, as shown in Table 2, indicated that about two-thirds of the attentive, interested, and residual science-oriented publics favored placing primary emphasis on orbital service systems under such conditions.

The 1979 survey asked each respondent to cite the benefits of space exploration. He or she could mention up to two benefits, and the following analysis includes both of those responses. The data indicated that the attentive public is most likely to see technological spin-offs and the discovery of new minerals and materials as major benefits (see Table 3). The interested public is the second most likely group to recognize these benefits.

With regard to basic knowledge about the universe, a third of the attentive public cited this benefit from space exploration, as did 22 percent of the interested public. Only 9 percent of the residual science-oriented public cited this result as a major benefit, despite their apparent high level of interest in science or technology.

It is clear from these data that the members of the attentive public are far better informed about the current and potential benefits of space exploration than are the other segments of the population. It should be noted, however, that the majority of both the residual science-oriented public and the non-attentive public could not name a single benefit of space exploration.

The 1979 survey also asked each respondent to cite up to two potential harms that might result from space exploration. The following analysis includes both of those responses.

The data indicated that the attentive public for space exploration was also more aware of potential hazards than were the other segments of the public (see Table 4). The major concern of the attentive public was the

Table 3
BENEFITS OF SPACE EXPLORATION: 1979

	ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Improve other technologies	44	35	12	8
Find minerals and other resources	40	13	8	5
Increase knowledge of universe	34	22	9	5
Find habitation areas	24	13	8	4
Contact other life forms	17	12	5	4
Raise food production and find new kinds of food	7	2	1	1
Find industrial use	6	4	1	1
Improve missile technology	6	6	2	2
Create economic benefits	3	1	1	1
N =	143	277	463	752

Table 4
POTENTIAL HAZARDS OF SPACE EXPLORATION: 1979

	ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Bring diseases or problems back	26	4	7	5
Waste money	17	3	4	5
Danger to astronauts	16	2	2	3
Disturb weather or atmosphere	15	5	4	5
Move warfare to outer space	11	1	3	1
Failing debris, garbage in space	9	1	4	4
Others conquer us through contact	8	1	3	1
Not biblical or will of God	1	1	1	1
N =	143	277	463	752

transmission of new diseases from space to the planet Earth, undoubtedly reflecting in large part the impact of Michael Crichton's *The Andromeda Strain*.[4] The attentive public was also sensitive to potential dangers to the astronauts themselves, to weather modifications, and to the cost of the program.

The interested, residual science-oriented, and non-attentive publics were able to name relatively few specific potential harms from space exploration. This result indicates that negative feelings toward the space program are rarely based on substantive information, suggesting that for those segments of the public other than the attentive public these views may be classified as "opinions" that are neither deeply rooted nor strongly held.

Can Attentives Have An Impact?

The major remaining question is whether the attentive public for space exploration can make a political difference with regard to either the NASA program objectives or to the level of funding. To deal with this question, it will be necessary to compare the political activities of the attentive public for space exploration with the other segments of the public. If the attentive public demonstrates a differential pattern of political behavior, it will then be necessary to fit those behaviors into the policy formulation processes characteristic of such non-electoral issues as space exploration.

Political Participation

Data from the 1979, 1981, and 1983 surveys indicate that the attentive public for space exploration is only slightly more active in direct electoral participation than other segments of the public, but that attentives are significantly more active in non-electoral participation—what James Rosenau calls "citizenship between elections."[5] Approximately three out of four citizens reported voting in at least one election—local,

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state, or national—in the last four years, and the attentive public was not significantly more active in this regard than other segments of the public (see Table 5). The attentive public was, however, significantly more likely to have made a political contribution to a candidate or party than were other segments of the population, suggesting that its members are indeed aware of the efficacy of political money and of the value of being remembered for their support.

In terms of overt partisanship, the data from the 1981 study indicated that the attentive public comprises almost equal numbers of Republicans and Democrats. About one in five attentives considered themself to be independent. This distribution of political loyalty provides a valuable bipartisan character for the activities of the attentive public for space exploration.

The most important facet of the political participation of the attentive public for space is the recognition of the importance of direct contact with decision makers in the formulation of public policy and the willingness to engage in that contacting process. Over one-third of the attentive public reported that they had contacted a public official on a policy matter, and 25 percent claimed that the contact involved a science-related policy matter (Table 5). When asked about the likely efficacy of contacting a public official, the attentive public was more optimistic that a personal contact would produce a desired policy outcome than were other segments of the public.

To better understand the stimuli to participation, the 1979 survey included a hypothetical policy dispute over the issue of seeking to communicate with other civilizations. Each respondent was told:

Let's suppose that one group of scientists wants to send radio messages into deep space to try to communicate with other civilizations, but another group of scientists believes that this could lead to conquest of our civilization by more advanced groups that might receive the signal. In a case of a conflict like this, which one of the groups listed on this card do you think would be the best qualified to decide the issue?

The data from the 1979 survey indicate that half of the attentive public would have relied on the advice of scientists and engineers who specialized in the area (see Table 6). The United Nations was cited second most frequently by the attentive public, with 17 percent indicating a preference for a UN decision. About 15 percent of the attentive public preferred to have the decision made by the administrators of NASA, and a similar percentage indicated a preference for a decision by citizens in a national referendum. While all four segments of the public deferred to the opinions of scientists and engineers who specialized in the area, NASA was the second most frequent choice for the three segments other than the attentive public.

The importance of the selection of scientists and engineers by the attentive public is that it is likely that the spokesmen for the major points of view on the issue would have come from the science and technology policy leadership group. The stratified model predicted that the attentive public would turn to this group, and the prediction was confirmed. The finding that all four segments of the public made the same choice indicates that reliance on ex-

Table 5
POLITICAL PARTICIPATION

	ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Voted in one or more elections in the last four years (1983)	77	80	81	75
Contributed money to candidate or party (1983)	41	31	34	25
Contacted a public official on a policy matter (1981)	36	26	24	16
Contacted a public official on a science policy matter (1983)	25	24	9	7
Perceived efficacy of contacting a public official (1981)				
Very effective	23	20	17	11
Somewhat effective	48	47	52	53
Mostly ineffective	29	33	31	35
Party affiliation (1981)				
Strong Democrat	14	15	15	16
Democrat	15 } 38	18 } 39	21 } 44	24 } 46
Independent Democrat	10	6	8	6
Independent	22	20	24	26
Independent Republican	10	10	6	6
Republican	13 } 39	14 } 41	15 } 33	14 } 29
Strong Republican	16	17	12	9
N (1981) =	327	490	838	1540
N (1983) =	155	327	599	550

pertise is deeply rooted in American society.

The 1979 survey used the same hypothetical policy dispute to ascertain the likelihood of personal participation in the dispute by the attentive public and the other segments of the public. Each respondent was asked to indicate the likelihood that he or she would personally take some role in the dispute, and the resulting data indicated that 66 percent of the attentive public would have participated in the dispute (see Table 5). In contrast, only 3 percent of the non-attentive public indicated that they would definitely participate, and an additional 17 percent thought that they might take some part in the dispute. The interested public reported the second highest rate of expected participation.

Priorities for Federal Spending

The most concrete and important point of public participation in the policy formulation process concerning space exploration is the federal budget process. With the adoption of revised budget approval procedures in Congress that require agreement on a government-wide expenditure ceiling, the process has become a zero-sum game: every interest must now compete against all other interests for a share of the available resources. It is at this point that the impact of attentiveness can be seen most clearly.

To allow an examination of public spending priorities for the federal government, the 1981 survey included a question that presented a series of programmatic objectives and asked each respondent to judge whether the government was spending too much, too little, or about the right amount on each area. On the question of space exploration, 57 percent of the attentive public for that issue reported that the federal government was currently spending too little on space exploration, and only 13 percent of the attentive public expressed the view that federal support for space was too high (see Table 7).

In sharp contrast, a majority of the non-attentive public indicated that the federal government was spending too much on the space program. On no other issue was the division between the attentive public (together with the interested public) and the non-attentive public so sharp.

As noted previously, the attentive public for space exploration is not a "single-issue" group. While 57 percent of the attentive public thought that the federal government was spending too little on space, a majority of the same attentive public expressed the view that the federal government was also spending too little on assistance to older persons, education, health care, and scientific research. Since a majority of all four segments of the population thought that the federal government was spending too little on assistance to older persons, health care, and education, the attentive public was a part of a broader national consensus on those issues.

On the question of spending for national defense, the attentive public for space exploration was badly split. Slightly over one-third of the attentive public expressed the view that the federal government was spending too little for national defense, while another third of the attentive public voiced the view that the federal government was spending too much for national defense. Only 29 percent of the attentives thought that the spending level was about right.

While these data set a context for federal spending that covers most of the major programmatic objectives of the federal government, the 1981 survey also posed the hypothetical circumstance of a stable level of federal resources for scientific research and development and asked each respondent to indicate whether

Table 6
ATTITUDES TOWARD RESOLUTION OF HYPOTHETICAL SPACE POLICY CONFLICT: 1979

	ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Best qualified to make decisions on space exploration				
A group of scientists and engineers who specialize in the area	50	55	48	49
The United Nations	17	7	8	7
The administrators of NASA	15	23	22	25
Citizens voting in a referendum	14	8	13	8
The president & Congress	3	7	7	8
The courts	1	1	1	1
Likelihood of personal participation in space policy dispute				
Definitely would	19	12	6	3
Probably would	47	40	27	17
Probably not	31	39	48	46
Definitely not	3	10	20	34
N =	143	277	463	752

he would increase, decrease, or hold constant the share of research and development funding for a series of programmatic areas within science and technology. Given those conditions, 69 percent of the attentive public indicated that they would favor an increased share of scientific research and development funds for space exploration, and only 7 percent supported a smaller share for space exploration (see Table 8). The interested public displayed essentially the same distribution of attitudes on the reallocation within science and technology question. The modal choice within the residual science-oriented public was to hold constant the share for space exploration.

Again, the attentive public for space exploration demonstrated a breadth of interest that went beyond the space program. A majority of the attentive public for space exploration also favored an increased share of scientific funding for disease-specific medical research, research on human learning, basic physics research, and basic chemistry research.

Table 7
SPENDING PREFERENCES FOR SPACE AND OTHER PROGRAMS: 1981

	ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Space exploration				
Too much	13	15	49	55
About right	30	42	41	37
Too little	57	43	9	8
Assistance to older persons				
Too much	2	3	3	3
About right	22	23	24	23
Too little	75	75	73	74
Education				
Too much	8	6	6	6
About right	36	35	31	30
Too little	56	59	63	64
Scientific research				
Too much	7	10	13	27
About right	41	44	54	50
Too little	52	46	33	24
Health care				
Too much	11	8	6	5
About right	37	31	33	32
Too little	52	61	61	64
Assistance to low-income presons				
Too much	33	24	23	25
About right	26	39	30	27
Too little	41	38	47	48
National defense				
Too much	33	22	31	26
About right	29	31	36	45
Too little	38	47	34	30
N =	153	254	405	763

Support for Space Exploration?

What, then, does all of this mean for the formulation of public policy in regard to space exploration? In the first place, it should now be clear that the original question is too global and not reflective of the policy formulation process. Space exploration is not a topic of high interest to the majority of American adults and is seldom an electoral issue. Rather, public policies toward space exploration are hammered out in traditional legislative and executive branch processes.

In this context, the active participation of the attentive public for space exploration in making direct contact with decision makers indicates both an understanding of the process and a willingness to play the game. The greater propensity of attentives to make political contributions to electoral candidates denotes the same kind of political savvy.

At this point, it is important to note that the attentive public infrequently initiates a wave of contacting behavior without some encouragement from the policy leadership group. Most of the people in the attentive public are busy with work and other daily goals, and the urge to write a congressman or to make contact with a public offical rarely surfaces without some stimulation from either the news media or a policy leader or group. In contrast, for example, a mailing from Carl Sagan on deep space probes or from the National Space Institute on funding for the shuttle program may mobilize an individual to make a direct contact on an issue. In general terms, I would argue that the policy leadership groups associated with space exploration are only learning how to play the game effectively and that their future political impact will be far greater than their past efforts.

What the data show is that there is a viable core group of approximately 17 million Americans who have a high level of interest in space exploration, who perceive themselves to be functionally literate in the area, and who hold very positive policy attitudes toward the space program. Further, the attentive public for space exploration appears to have an

Table 8
BUDGETARY DISTRIBUTION PREFERENCES WITHIN SCIENCE AND TECHNOLOGY

		ATTENTIVE PUBLIC FOR SPACE EXPLORATION (%)	INTERESTED PUBLIC FOR SPACE EXPLORATION (%)	RESIDUAL SCIENCE-ORIENTED PUBLIC (%)	NON-ATTENTIVE PUBLIC (%)
Space exploration:	D	7	13	34	NA
	C	24	30	43	NA
	I	69	58	23	NA
Disease-specific medical research:	D	2	1	2	NA
	C	14	17	15	NA
	I	84	82	84	NA
Human learning:	D	8	6	5	NA
	C	28	31	24	NA
	I	64	64	71	NA
Basic physics:	D	7	6	10	NA
	C	41	43	56	NA
	I	52	51	34	NA
Basic chemistry:	D	4	4	7	NA
	C	46	45	47	NA
	I	50	51	47	NA
Engineering:	D	4	5	5	NA
	C	50	42	53	NA
	I	46	53	42	NA
Human behavior:	D	20	20	19	NA
	C	43	42	39	NA
	I	38	38	42	NA
Weapons:	D	25	20	26	NA
	C	37	33	34	NA
	I	38	46	40	NA
Mathematics:	D	12	12	18	NA
	C	55	47	55	NA
	I	33	41	28	NA
N =		327	490	838	1,540

LEGEND: D = decrease funding
C = hold constant funding
I = increase funding

understanding of the rules of the game for the practice of politics between elections and some track record of making personal contacts with decision makers. The potential for the mobilization of this group is far greater than its previous utilization.

Intuitively, many people feel uneasy about a core group of only 10 percent. Is this enough? Should the policy leadership groups be actively seeking to expand it? The answer is not simple, but it is worth noting that the attentive public for space exploration is about the same size as the attentive public for foreign policy (there is some overlap, of course) and larger than the attentive public for agricultural policy. On the other hand, it is only half as large as the attentive public for broader science and technology issues and about one-third of the size of the attentive public for economic policy.

On balance, I would say that the current attentive public is large enough to be effective in the policy-making processes when effectively mobilized by the leadership groups. At the same time, it never hurts to have a somewhat larger group. The data outlined previously suggest that there are at least 34 million additional citizens who have a high level of interest in space exploration but who do not feel adequately informed about the area. An aggressive, long-term program to identify and communicate with this group would almost surely increase the size of the attentive public for space exploration.

Further, there are additional millions of citizens who are very interested in science in general but who do not find space exploration to be a topic of interest. To the extent that this group can be persuaded of the importance of the scientific mission of the space program, some of those individuals might be expected to develop a continuing interest and knowledge base about space matters.

Looking at the question of public support for space exploration in the broader context of the political process, it would appear that there is a strong core segment of the public committed to the support and advancement of space exploration. In the absence of an organized opposition to space exploration, the attentive public for space is likely to exercise considerable influence. To effectively employ this group, however, it will be necessary for the policy leadership group to better understand the non-electoral policy-making process and to more consciously address the identification and cultivation of the attentive public for space exploration.

NOTES

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Why NASA's space shots don't reach for the stars.

MISSION OUT OF CONTROL

BY TINA ROSENBERG

WHILE Neil Armstrong was taking his giant step for mankind on the Moon in 1969, the National Aeronautics and Space Administration was soaring back on Earth. By meeting President Kennedy's 1961 challenge to land a man on the Moon within the decade, NASA had proven communism was no match for American know-how and the American way of life. A decade of race riots, assassinations and war culminated with the stars and stripes planted in the Sea of Tranquility.

But following the Moon landing, NASA went through a postpartum depression on a grand scale. Employment in the space program, once 420,000, declined to 160,000 by 1971. Laboratories closed. NASA's budget, once nearly $6 billion, dropped to slightly more than half that amount. After enjoying high status, the excitement of working on a top-priority challenge, and all the money it needed, NASA was faced with the question: Now what?

The agency responded by asking for the moon. In 1970 and 1971 NASA requested money for a reusable space shuttle to carry cargo to space cheaply, and for a 100-man orbiting space station by 1980, and for a $24 billion manned mission to Mars, and for a commitment to a lunar base. To fill in what it thought would be a gap in manned space flight between the last Apollo mission and the start of the shuttle, NASA even proposed a mini-shuttle, which it admitted had limited use.

In short, NASA had gotten hooked on the size and glamour of manned programs. It's easy to see why. NASA was—and still is—convinced that only manned missions can focus public interest in space and persuade Congress to fund NASA's programs. "Supporting astronomy is like supporting ballet," says Alexander Dessler, director of the Marshall Space Flight Center in Huntsville, Alabama. "There's no clear, immediate benefit." But by showing Americans performing dangerous missions in space, NASA captured public attention with a human drama. NASA has always understood the P.R. value of human derring-do. When choosing astronauts for its first manned program, Mercury, NASA tried to find candidates who fit the public's conception of clean-living All-Americans who could represent the United States in its race with the Russians. Once the astronauts were chosen, *Life* magazine airbrushed their lives, and NASA changed their role from passenger to the more heroic job of pilot. Astronauts can also make speeches and testify before Congress—a skill no satellite will ever master.

But public attention is not the only advantage NASA gets from manned programs. "It's difficult to know where the public interest in seeing man in space stops, and NASA's inclination to keep people employed starts," says a Senate staffer. No. 1 on NASA's current list of eight goals is "maintain the institution."

If NASA wants to keep its scientists and engineers busy, the best way is through manned programs. Manned spacecraft are larger, more expensive, and more time-consuming to build than unmanned vehicles because they require food, water, oxygen, and back-up systems that are not needed for unmanned vehicles. Manned vehicles need to bring astronauts safely back to Earth, which necessitates more tests, longer trips, and re-entry hardware such as heat shields. Most important, a manned program, unlike a scientific program, usually implies a commitment to multiple launches and ambitious space goals.

NASA not only worries about employing its own personnel, it also looks out for the aerospace industry. As with the Pentagon, the line between government and industry blurs when the two work together on twenty-year projects. "We work so closely together that we jokingly call ourselves 'partners-in-crime,' " says Peter Eaton of NASA's Expendable Launch Vehicle office, speaking of NASA and the McDonnell Douglas Corporation, which makes the Delta rocket. It is commonplace for NASA to recruit industry engineers and for NASA officials to leave the agency to work for a contractor.

Although NASA had asked in the early 1970s for funds for just about every manned project imaginable, Congress and President Nixon did not comply. With his budget stretched by the Vietnam War, Nixon approved only the project NASA touted as a money-saver: the space shuttle. The shuttle, it was claimed, was a kind of cheap, efficient truck that would haul materials and satellites into orbit. It would be less expensive than expendable rockets because while it would need a new fuel tank and refurbished booster rockets for each mission, the airplane-shaped orbiter would be reusable. At a development cost set for $5 billion and a much lower operating cost than disposable rockets, the shuttle would lower the cost of

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Tina Rosenberg is a Washington writer. Her most recent article for TNR was on the federal budget ("Figure Skirting," February 13).

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commuting to space and therefore of all future space missions.

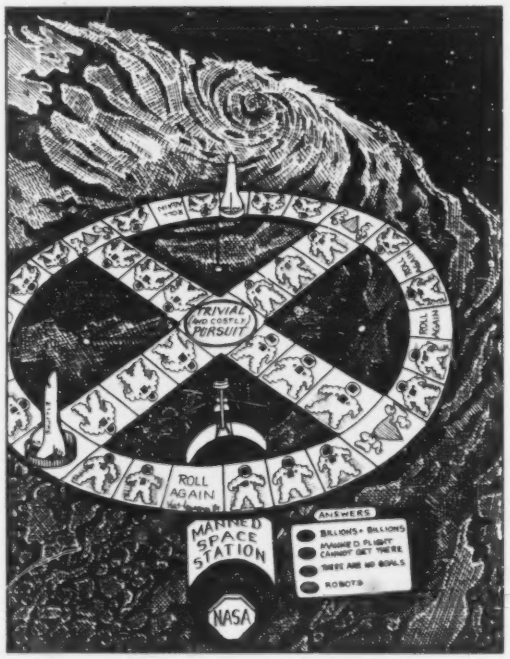
From the beginning the shuttle proved balky. Scheduled to launch in 1977, it didn't make its first test until April 1981 and wasn't operational until November 1982. By the time the shuttle was open for business, development costs had ballooned from $5 billion to $15.5 billion. NASA is still ironing out minor problems, but the shuttle's real flaw won't go away: it's no cheaper to operate than NASA's old Chevy, the Delta rocket.

At first glance, the shuttle does look cheaper than launching the same payload with the Delta. Let's say your commercial firm wants to launch four communications satellites in 1986 into geostationary orbit (G.S.O.) 22,000 miles above the equator. At G.S.O. a satellite rotates with the Earth—a satellite placed over Quito, Ecuador, stays over Quito, Ecuador. With the Delta, each launch will cost $25 million. Total price for launching four satellites: $100 million.

The shuttle can carry four times the Delta payload, but it requires a two-stage trip because it orbits a mere 350 miles up, practically skimming the Earth's surface. To kick your satellite up to G.S.O., you need a Payload Assist Module, or PAM. (The PAM is the part that malfunctioned two flights ago and flung two satellites into the wrong orbit in the process.) Each PAM will cost $4 to $5 million, for a cost of about $18 million for four. From 1986 through 1988, you can book the whole shuttle—enough for your four satellites—for $79.4 million. So for your 1986 shuttle mission to G.S.O., you will pay a total of $97.4 million. You save all of $2.6 million over the cost of Delta rockets.

But what's important to recognize about the shuttle is that price to customers has no relation to the actual cost of the shuttle. "For realistic missions during the next twenty years or so, the shuttle system is actually more expensive than are conventional, expendable boosters," Dr. James A. Van Allen, professor of astronomy at the University of Iowa wrote in 1982. The shuttle looks cheaper because NASA subsidizes its missions.

It wasn't meant to be that way. Shuttle prices were set in 1972, when NASA predicted there would be 572 flights. The problem is that the shuttle won't fly 572 missions; NASA now estimates only 234 missions before the machine is ready for the Smithsonian. That gives NASA fewer flights over which to amortize the cost of building the shuttles and a shorter time in which to learn to operate more efficiently. As a result, costs have soared—this year, each shuttle launch costs $200 million. NASA had planned to raise the price of post-1988 missions to recoup the money it is losing now but NASA has changed its mind. NASA senior staff engineer Barbara Stone says that by 1988, the shuttle will still cost over $100 million per flight—too much for NASA to charge and stay competitive. "I don't think we'll recover those cost underruns," Stone says.



DRAWING BY VINT LAWRENCE FOR THE NEW REPUBLIC

NASA claims the shuttle can save money another way, by repairing and redeploying ailing satellites. In April, shuttle astronauts repaired the Solar Maximum observatory. But the shuttle can only reach satellites in or near low Earth orbit, which is where Solar Max was stationed. The vast majority of satellites are in G.S.O., a good 21,650 miles beyond the shuttle's reach. And what NASA does not mention is that there was no reason to build the shuttle to host satellite repair missions. Expendable rockets can do the same job, and they can travel to G.S.O. According to Arthur Koski, spokesman for the Martin-Marietta Corporation, which worked with NASA to repair Solar Max, the only reason rockets can't do repair missions is that we don't have any. "Our only manned spacecraft is the shuttle," says Koski. "And at this point it wouldn't make much sense to build rockets."

NASA's last commercial Delta launch is scheduled for the end of this year. By getting rid of the Delta program NASA will no longer steal business from itself. But the

shuttle still faces competition from emerging for-profit rocket companies. NASA is putting the finishing touches on an agreement with a private company, Transpace Carriers Inc., to take over existing contracts for the Delta. The company plans to make its first launch in 1985 or 1986. NASA already has competition from the European Space Agency's Ariane rocket. Arianespace has one model, the Ariane 3, that can throw half the shuttle payload (or two Delta payloads) into G.S.O. for $25 million, including the boosters. Total cost of a shuttle-sized payload: $50 million. And because Ariane is out to make money, that is not a subsidized price. Western Union, GTE, and INTELSAT among others have launched satellites on Ariane.

Why can Ariane deliver at half the shuttle's price? "We're not a man-rated vehicle," explains Jean Michel Eid, assistant manager of Arianespace in America. It's people and the life support and safety systems they require that keep the shuttle from lowering the cost of space travel.

Now that the shuttle is working, NASA is at another critical point: the decision of what to do next. Keeping in mind the advantages NASA reaps from manned programs, agency administrator James M. Beggs chose the space station. When he first asked for funds he ran into a wall. The Space Science Board of the National Academy of Sciences said a space station had no scientific purpose. The Pentagon said it had no military purpose. David Stockman, director of the Office of Management and Budget, thought it was too expensive, and the science adviser to the President, George Keyworth, thought it was too boring to generate the kind of excitement the Apollo mission had created. Fortunately for NASA, Beggs found a believer in President Reagan, who endorsed a permanently manned space station in his State of the Union Address and put seed money for it in his 1985 budget.

BEGGS CONVINCED Reagan of what has become NASA's guiding vision: a modern version of manifest destiny that sees Americans living and working in space. This philosophy is almost devoid of any idea about what we will do there. Being there, apparently, is enough. At a November 1983 Congressional hearing, T. F. Rogers of the Office of Technology Assessment testified, "To our knowledge, there is no comprehensive and thoughtful list of goals." On NASA's twenty-fifth anniversary in the fall of 1983, Beggs wrote, "I believe that a space station, is, indeed, an idea whose time has come. Sooner or later, this country is going to take the next logical step in space and will build one. And the sooner we do so, the better it will be for us, because a space station is essential if we are to maintain our preeminence. I see a space station as an essential stepping-stone to the future."

NASA has what seems to be an enlightened attitude toward space: a place where poets and painters as well as scientists can work. "I'm not prejudiced," says Hans Mark, deputy administrator of NASA. "I see a future where people doing things not associated with space will go there. It is the obligation of any great civilization to support the arts."

If you happen to be the poet or pioneer chosen to live in space, this idea is exciting and romantic. If you're the taxpayer signing the lease for this high-rent suburb, however, its appeal pales somewhat. Cost is something space visionaries never seem to think about. Never mind that settling the Sahara would cost far less than housing a large number of people in orbit. Never mind that you could keep thousands of artists from starving on Earth for the price of putting one a little bit closer to the stars. The idea of a space colony allows NASA to view manned missions as their own justification, at the expense of commerce, science, and exploration.

SPACE travel has never quite lived up to its billing as a technological bonanza. The science and engineering feats it encourages have only limited use here on Earth. Trickle-down technology is not an efficent way to regain our competitive economic edge. And the spin-offs space has given us such as hand-held calculators, digital watches, phone calls via satellite, improved computers—just about everything except Tang—have come from programs that have one thing in common: they were unmanned. "There's an inverse relationship between the payoff of a mission and the importance of man," says Wallace A. Berger, staff director of the Senate subcommittee that oversees NASA. "An overemphasis on manned missions forecloses advancing science or producing something of commercial value."

This is because building new ways to carry men in space offers little of value to earthlings. The shuttle's efficient engines that burn super-cold hydrogen and oxygen, for example, have no other use except in the dubious cause of the MX missile. In contrast, unmanned planetary probes have spawned new ways to send information and pictures over very long distances, the basis for new communications technologies. Moreover, designing missions for men creates less technological innovation than creating an automated mission to do the same tasks. If an astronaut is around to change the film in an observatory camera, there is no reason to develop the robotics to do it automatically.

Recently, speculation about the commercial benefits of space has centered on taking advantage of space's zero gravity and near-perfect vacuum to process new metal alloys and pure chemicals. NASA sees the space station as a space factory. But just as with the shuttle, the manned space station faces competition from cheaper, easier to build, unmanned space manufacturing platforms. The key to economically viable space manufacturing is doing the job more cheaply than on Earth. That means robotics. While manned work might be prohibitively expensive, an automated mission at one-twentieth the cost could make space processing profitable. The Fairchild Corporation is developing an unmanned space platform

called Leasecraft which it hopes to launch in 1987—about seven years before NASA's space station is supposed to be ready.

One of the first tests of Leasecraft's commercial potential will be electrophoresis, a gravity-free way to make pure pharmaceuticals, developed jointly by Johnson & Johnson and McDonnell Douglas. Electrophoresis is the best-developed space manufacturing process, and manned space station supporters invariably mention it as a project that they could put in orbit. But far from needing a manned space station, electrophoresis is fully automated, needing only periodic human tending—and there is a good chance its manufacturers will sign with Leasecraft. (It's no surprise that NASA is now exploring the idea of launching an unmanned space platform.)

INSTEAD OF encouraging cost-effective automatic work, the space station will subsidize an inefficient method of processing. "It's like buying an expensive car, pretending it didn't cost you anything, and comparing it to the cost of taking a taxi," says Richard Garwin, former science adviser to President Carter. "When you offer free passage, people will take you up on it." And just as with the shuttle, if NASA stops subsidizing industry and charges prices that reflect the space station's true costs, it will lose the price war with unmanned platforms.

More harmful than the manned program's effect on commercial industries is its impact on space science. The space station just won't support an adequate scientific laboratory. The first problem is that the space station must stay in low Earth orbit, too low for many experiments. For example, the space station can't do experiments on the solar wind (vast currents of ions that affect the weather and telecommunications) because it can't reach the solar wind. But more crippling, it is manned. "All experiments and observations can be done equally well or better by instruments than by men," says Dr. Thomas Gold, a Cornell University physicist. "For observations, the presence of a man is a disaster. He can't keep still enough." The advantage of having a telescope where no atmosphere distorts light is lost if there are humans tromping around literally rocking the boat.

There are, of course, experiments you need men for: experiments on men. But that's about all. Communications and robotics have become sophisticated enough so that experiments can be tended by remote control from Earth about as well as by men in a capsule. Ask scientists what kind of missions they would choose to do their experiments, and they will say small, unmanned (and cheaper) go-anywhere capsules built to the specifications of particular experiments.

The debilitating impact of the shuttle and the space station is even greater where exploration is concerned. Because of the moon shot, the public has come to confuse "exploration" with "manned exploration," a mistake NASA does little to correct. In fact, *unmanned* exploration is the best way to expand our space horizons. Take one of NASA's most ambitious goals, a manned expedition to Mars. Thanks to the Viking Mars lander we have charted Mars' weather, atmosphere, soil, and volcanoes. For almost any space mission, unmanned probes with cameras and scientific equipment can find as much about a new surface or atmosphere as a man can learn. It's not the next best thing to being there—it is being there. "Instead of seeing the surface directly, you'd see it through a TV camera," says NASA's Dessler. There are only two differences between manned and mechanical exploration. One is that manned missions cost twenty to thirty times more than unmanned missions; Sally Ride on Mars would be nothing more than a $100 billion flag-planter. The other is that to most places we want to go, such as Venus or Jupiter, we can send instruments—and we can't send men.

The most lofty justification for manned space travel is that it satisfies, as all "Star Trek" fans know, the urge "to boldly go where no man has gone before." But a mission to Mars would be timidly revisiting a place we went years ago. As an expression of the human spirit, manned space exploration is rather complacent. Preferring a lunar base to real exploration is like Columbus saying to Queen Isabella, "I'll pass on the ships but why don't you give me some money to take a Mediterranean cruise?"

Even if we do want to prepare for future manned missions, the space station is the wrong first step. We already know how to acclimate humans to space life, and we know how to build rockets in space. Our challenge is to find a sufficiently powerful propulsion method to travel throughout the solar system. A space station can only launch deep space travel after that problem is solved.

THE REAL *Niñas* and *Pintas* today are unmanned observatories and planetary probes. And the cost overruns of the shuttle drained money from their important missions; the space station is threatening to do the same. Because of the shuttle, the United States is not launching a probe to sail through the tail of Halley's comet in 1986 and gather samples, as the Soviets and Europeans are doing. NASA canceled the Mars Rover, which would have scooted around Mars' surface and brought back samples from many sites. It canceled the Grand Tour, a satellite mission that would have taken advantage of an alignment of all the outer planets that won't occur again at least until the year 2110. It canceled the Mariner mission to study the mysteries of Jupiter's atmosphere and to give us a first glimpse at the moons of Uranus. The United States has withdrawn our satellite from the International Solar Polar Mission leaving just one European probe to fly past regions of the sun which we have never seen before. NASA has also abandoned the Sun Blazer, a proposed craft that would have flown within 4 million miles of the sun's surface.

Ten years and $20 billion from now, when the space station is operating, what can we expect? Almost certainly, NASA will ask for that manned Mars mission or lunar base, invoking words like "American preeminence" and "fulfilling our destiny." But what NASA will not talk about is how little its projects will capture the wonder and romance of true space exploration.

SPACE SCIENCE RESEARCH IN THE UNITED STATES

A TECHNICAL MEMORANDUM

SEPTEMBER 1982

Technical Memoranda are issued by OTA on specific subjects analyzed in recent OTA reports or on projects presently in process at OTA. They are issued at the request of Members of Congress who are engaged in committee legislative actions which are expected to be resolved before OTA completes its assessment.

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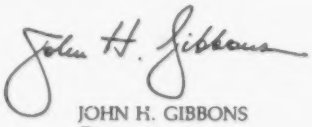
CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

Preface

Selective budget cuts and reallocation of funds within the National Aeronautics and Space Administration's space science program have left planetary science, solar and heliospheric physics, gamma ray astronomy, and X-ray astronomy with uncertain futures. Indeed, many in the space science community think that the program has lost its sense of direction and that it is time for national goals for space science to be articulated. Responding to this concern, Rep. Cooper Evans of Iowa requested the Office of Technology Assessment (OTA) to examine the direction and purpose of the U.S. space science program. In particular, Rep. Evans asked OTA to "assist Congress in evaluating the effectiveness of our space science program and in discovering what its future needs are."

In undertaking the study, OTA sought the contributions of a wide spectrum of knowledgeable and interested parties. To this end, a questionnaire, designed to elucidate the issues and problems in the current conduct of the U.S. space research program, was sent to representatives of several Federal agencies, space scientists, and staff members of congressional committees and individual Congressmen. Over 80 formal replies were received. Concurrently, OTA arranged a number of separate meetings and discussions with these three groups for additional detailed evaluation of the issues. These various contributions were then organized into background reports which served as the basis of a workshop held at OTA on May 5, 1982.

The following technical memorandum summarizes and critiques the views of many people interested in space science, several of whom attended the workshop. In preparing this document, OTA did not attempt to obtain the views of those who are opposed to or uninterested in space science, nor did OTA attempt to rank space science against other national priorities.



JOHN H. GIBBONS
Director

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OTA Space Science Research in the United States Project Staff

John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

William Mills, *Program Manager*
Space, Transportation, and Innovation Program

Philip P. Chandler, II, *Project Director*

William E. Howard, III*

Contributor

Ray A. Williamson

Administrative Staff

Paula Walden Marsha Fenn
Jannie Coles R. Bryan Harrison

OTA Publishing Staff

John C. Holmes, *Publishing Officer*

John Bergling Kathie S. Boss Debra M. Datcher Joe Henson

*On detail from the National Science Foundation (February-August 1982).

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Chapter 1

Summary

The information presented in this document derives primarily from consultation with a wide spectrum of people involved in space science. In undertaking this study, OTA did not obtain the views of those outside the space science community, nor did OTA attempt to rank space science against other national priorities.

CURRENT SITUATION—DESCRIPTIVE

Despite its many noteworthy achievements over the past 20 years, the space science program of the United States has, as a whole, been placed in a holding pattern and, in significant parts, been forced to retrench. Many now see space science as in a state of crisis. The National Aeronautics and Space Administration's (NASA's) overall budget for space science has, in general, been on the decline since 1974 (see app. C), and that of one category, planetary science, has declined precipitously. For the latter part of this period, the space science budget for physics and astronomy has been on the rise, but this increase is largely being spent on a single major project, the Space Telescope.

As a result, few missions are in prospect: in planetary science, only the major Galileo mission to Jupiter is planned for the 1980's; in solar and heliospheric physics and X-ray and gamma ray astronomy, all major missions have been postponed. Not only have the numbers of missions decreased, but there is insufficient funding for important interim activities such as data analysis. Thus, there is an uncertain future, not only for planetary science, but also for several subdisciplines which fall under the rubric of physics and astronomy.

Two additional factors make the situation particularly acute. First, most research activities follow a cycle in which new subdisciplines are born, grow to maturity, and then taper off into a continued, but reduced level of activity. But space science, as a relatively new field of research, finds itself with all of its subdisciplines still ripe for further growth. No space science subdisciplines have yet reached a point of naturally reduced activity. Given this situation, the general truth that, with a relatively constant level of overall funding, growth of some subdisciplines can occur only at the expense of others, becomes of particular concern. Second, as the number of missions has declined, those that remain have tended to be more complex, sophisticated, and expensive, and have tended to squeeze out the smaller and less expensive missions which have in the past supported a broad research base. These two factors, taken together, make it difficult for a number of productive teams of researchers in universities and in industry to remain viable.

CURRENT SITUATION—ANALYTIC

In all U.S. pronouncements on space policy, from the 1958 National Aeronautics and Space Act to the White House Fact Sheet on National Space Policy, released on July 4, 1982, continuing progress in space science is cited as a national goal. Because of this general policy, space science receives some portion of the Federal budget for space activities. Unlike the manned program, however, space science has never been directed toward a particular goal of unequivocal priority. Without the kind of commitment that arises from acceptance of a challenge to meet a particular goal, space science research has been conducted in a mode where the programs undertaken are determined primarily by whatever budget is made available (the levels of which fluctuate wide-

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ly) and only secondarily by scientific goals. Furthermore, even within the budget made available for all of space science, the importance of certain scientifically critical activities has not always been recognized. As a result, no base budget has ever been set to ensure that these activities are sustained.

The impacts on space science from the manned program are often substantial. Large development programs, like Apollo or the Space Transportation System (space shuttle), are undertaken as national political commitments, and therefore have the highest priority within NASA. When these programs experience cost overruns, they tend to draw funds away from NASA's other programs, including that of space science. When there is pressure to move funds out of space science into other parts of NASA, the purely scientific activities—data analysis, theory, and mission design—are the least protected.

An analogous problem exists *within* the space science program in that large science projects, like Viking or Voyager, tend to draw funds away from the smaller ones. A significant measure of the past success of NASA's space science program has resulted from a balance of large and small projects undertaken at the same time; a certain concern, therefore, must attend the possibility that, with limited total funding, the few remaining projects may be large, leaving no support for small ones. There is an additional concern that, especially with approval of new-start status for small missions at least as difficult to achieve as for large ones, missions originally designed to be small tend to grow into relatively large ones. The Space Test Program, operated by the U.S. Air Force for the Department of Defense, could provide a model for a renewed NASA effort to design a series of small-scale, productive missions that would remain small.

At the present time, funding allocation for post-mission data analysis is generally insufficient to permit optimal use of data returned from spacecraft. Relative to the total cost of a given mission, the cost of analyzing the data returned is small. Given the current practice of combining the budget for science per se with the budget for hardware, some have suggested a minor reallocation of mission funding, in which a modest reduction in overall mission capability would free additional funds for data analysis, as a way to ensure an improved scientific return. Alternatively, a base budget for science, including support for data analysis, might also solve the problem.

The budgetary situation of space science has been characterized by major fluctuations caused, in large part, by pressures originating in other areas of the space program. Planning for space science, therefore, even if it is extensive, is not necessarily effective over the long run. Every effort should be made to avoid situations in which plans are made on scientific grounds and then modified later on nonscientific grounds. At a minimum, the science will suffer; to the extent that expenditures have been made, there will also be monetary loss. In addition, because many efforts are interrelated, changing one may affect others, sometimes substantially. Finally, failure to see a project through to completion can adversely affect the careers of the scientists involved, often requiring them to reorient their research programs, and can damage the prestige of the Nation, particularly when international agreements are broken.

International cooperation in scientific activities has been fruitful in the past and, for possible major missions in the future, may be highly desirable in order to share costs. International partners, however, perceive a problem of the United States reneging on commitments to international missions, including commitments made by Congress. As a result, they are reluctant to enter future agreements with the United States. This situation is likely to continue until better assurance can be given that U.S. commitments made to international space science missions are honored.

POSSIBLE NEW DIRECTIONS

The current practice of budgeting most flight missions as independent new starts emphasizes spectacular accomplishments, and is not necessarily optimal for scientific progress. This practice has perhaps been perceived as necessary in the absence of a national commitment to particular space science goals. The alternative most often discussed—what might be termed the programmatic approach—differs in at least two respects.

First, budgets for important continuing activities (including instrument design, data analysis, theory, and perhaps small- to moderate-sized missions) would be separated from (and thereby protected from cost overruns in) the budgets for major missions (including hardware, launch, and mission operations). With this separation, scientifically valuable, but unspectacular activities could be sustained even in times when overall funds are strictly limited; missions to take advantage of unique opportunities could be supported as the overall budget allowed.

Second, missions for each discipline would be designed primarily in accordance with long-term scientific needs. Especially with a commitment to particular scientific goals, the programmatic approach might make the entire space science effort—planning, execution, and data analysis—more effective.

In the opinion of many space scientists it would be advisable to place the responsibility for scientific projects as nearly as possible in the hands of the principal investigators. The current management scheme for the Space Telescope Science Institute provides an interesting example (and test case) of how scientists themselves may undertake the long-term operation of a major research facility.

The boundaries that formerly justified NASA's being the lead agency for the space-based efforts in space science and the National Science Foundation's playing a similar role for those that are ground-based are becoming increasingly arbitrary. There is some indication that a cross-agency advisory mechanism would be useful in adjudicating jurisdictional questions that occasionally arise among these and other agencies responsible for various space science activities and in ensuring a balanced, nonduplicative space science effort. One possibility for addressing problems of coordination would be to broaden the charter of the Space Science Board (SSB) of the National Academy of Sciences to include determination of priorities of all activities in space science, not just those proposed for NASA.

The current crisis in space science might well be an opportunity for SSB to take stock of the details of the problems indicated in this technical memorandum. An initial task would be to give a clear accounting of the numbers of people engaged in space science, and of their distribution; analyses of the effects of reduced or level funding on research groups could be undertaken. Information relating to these matters is still largely anecdotal. Without this information, the present health of space science research in the United States cannot be precisely assessed, nor can its future needs be predicted.

Overall, it seems desirable for SSB or some other duly constituted body to begin a more thoroughgoing effort to set scientific priorities for space science within a framework of possible budgetary alternatives. If this were done in a context in which: 1) one budget would be set for continuing activities that are scientific per se, and 2) another budget for missions would be separately negotiated, scientific expertise might be brought to bear on the choice of space science activities more effectively.

Chapter 2

Current Situation in Space Science

Over the past quarter century the United States has developed a scientifically productive space science program. The largest number of missions have been dedicated to solar and solar-terrestrial physics; as a result of this sustained work, scientists are developing a good understanding of Earth's magnetosphere and its interactions with many solar phenomena. The Mariner, Pioneer Venus, and Viking missions have been flown to our neighboring terrestrial planets, Mercury, Venus, and Mars; Pioneer and Voyager spacecraft have returned a vast array of important and exciting data from Jupiter and Saturn in the outer solar system. The planned launch of the Space Telescope will increase our knowledge of the farthest reaches of the universe with imaging capabilities never before achieved in optical astronomy.

Over the past few years, however, there has been a significant downward trend of budgetary support for one subdiscipline* of space science, planetary exploration. (See app. A.) Recent budget cuts have now called into question the continuation, survival, and future viability of the U.S. planetary science program. In the view of the planetary scientists, the program is in danger of complete collapse. If the present trend in funding were to continue, the planetary science program would be extinct by the end of the decade.

In spite of the apparently greater resources at their disposal, problems confront solar and heliospheric physics, and X-ray and gamma ray astronomy, all of which have had their major missions deferred. Overall, only the launch of the Space Telescope and a possible repair of the Solar Maximum Mission remain in prospect. Indeed, there is no assurance that the United States will fly a major space science mission after the Space Telescope.

It was widely held in the OTA workshop that current funding for space science makes it impossible to maintain all the subdisciplines at viable levels. There is some possibility, however, that a relatively minor reapportionment in funding from hardware development to postmission data analysis could be a useful interim measure. Despite its best efforts to provide a balanced space science effort, the National Aeronautics and Space Administration (NASA) has found it necessary to reduce support in planetary research in an attempt to maintain previous commitments within the agency and to maintain the viability of the remaining projects.

Space scientists are especially concerned by four immediate problems:

1. lack of flight opportunity;
2. uncertain commitment to the range of disciplines;
3. lack of support for postmission data analysis; and
4. threatened loss of data from existing spacecraft.

None of the disciplines of space science escapes the threat posed by these elements.

The area of most pressing concern to scientists, however, has been planetary exploration, where effected or proposed funding cuts of 50 percent in mission operations and data analysis and 30 percent in research and analysis, between fiscal year 1981 and fiscal year 1983, are resulting in significant reductions in basic research in planetary science programs at universities and NASA centers; if inflation is taken into account, these cuts are significantly larger. Some research laboratories and institutes such as the Jet Propulsion Laboratory, which have been operating for many years, may have to direct their efforts into other fields.

These cuts have seriously threatened to terminate productive, active spacecraft (Pioneer Venus Orbiter and Pioneers 10 and 11). Because of the current situation in planetary science funding, no experimenter can with any reasonable degree of assurance foresee the time when his experiment, if selected, will fly; no laboratory scientist can feel confident that a new research project will be funded long enough to come to fruition.

*In this document the word "subdiscipline" is taken to mean any branch of recognized disciplines; thus, X-ray astronomy is a subdiscipline of astronomy.

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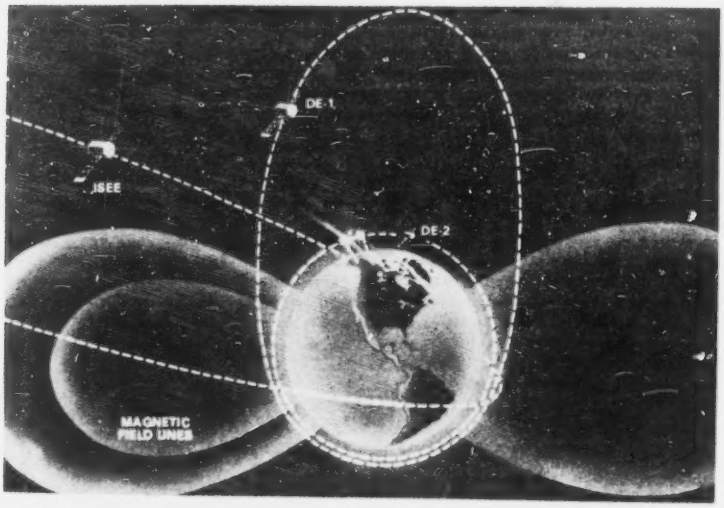
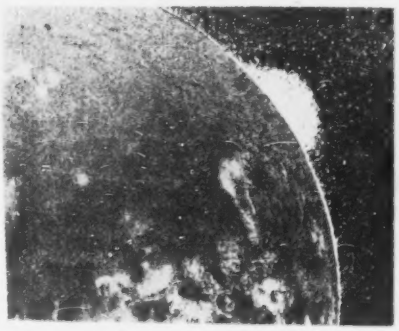
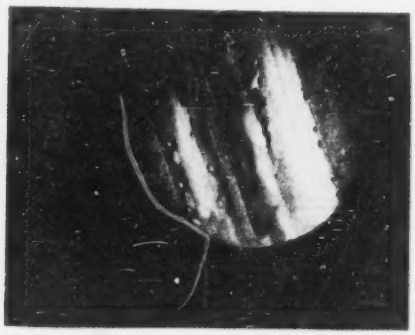
The Diversity of Space Science



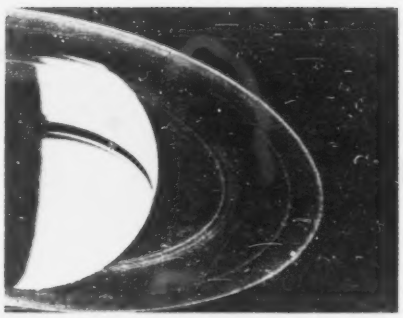
By releasing visible metal vapors at altitudes of about 1,450 km, NASA scientists were able to measure the electric fields that cause auroras in the underlying ionosphere by accelerating charged particles along the Earth's magnetic field lines. Measurements were made Apr. 12 and 26, 1982, by particle detectors aboard two Dynamics Explorer satellites

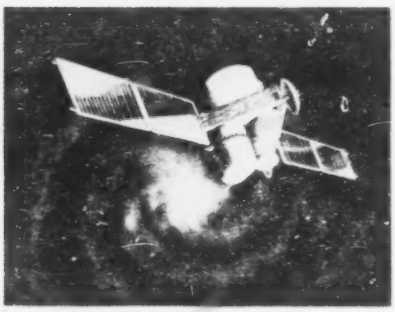


Region of volcanic eruption on the Jovian satellite Io is pictured from data returned from Voyager I's encounter with Jupiter, Mar. 4, 1981



Jupiter, its Great Red Spot, and three of its four largest satellites are visible in this photo taken Feb. 5, 1979, by Voyage I, when the spacecraft was 28.4 km from the planet. The innermost satellite, Io, can be seen against Jupiter's disk





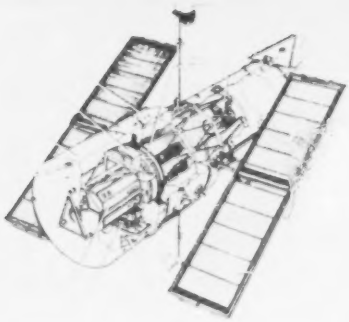


Photo credits: National Aeronautics Space Administration

Top: Litter on Mars: the shroud which protected the surface sampler instrument on Viking II during the spacecraft's year-long journey from Earth lies shining on the Martian surface after its ejection

Middle left: Image of the far side of Saturn and its rings, returned by Voyager II on Aug. 29, 1981

Middle right: Artist's conception of the Gamma Ray Observatory

Lower left: The Space Telescope, to be launched into orbit from the Space Shuttle, will allow scientists to gaze seven times farther into space than ever before

Throughout space science this problem is compounded by the maturation of the several space science disciplines. At present funding levels, the frequency of new missions for each major discipline has already decreased to about one per decade per discipline. The disciplinary category of planetary exploration and the subdiscipline of X-ray astronomy are perhaps affected the most by this situation; solar-terrestrial research and the atmospheric sciences also are approaching a critical level of support. Increasingly, universities and industry are assessing the opportunities to be so minimal that they will no longer pursue them; as a result, experienced scientists are leaving these fields, and students and other new researchers are not entering them.

This situation has been caused in large part by a trend toward fewer, more expensive missions. During the earlier stages of the national space program, there was, at least in the astronomy and physics disciplines, a broad mix of relatively inexpensive science opportunities (including experiments on sounding rockets and balloons) and facilities-class spacecraft (Orbiting Geophysical Observatories, Orbiting Solar Observatories, Orbiting Astronomical Observatories, Interplanetary Monitoring Platforms, Pioneers, etc.). This mix allowed for an active, growing community to do important, productive work. If one group failed to qualify for flight on a major observatory spacecraft, it might still qualify for a small project, in which the group could still maintain productive activity and could develop plans for the next major opportunity. Today, however, failure to qualify for a major mission is extremely detrimental to the long-term continuity of the proposing group, for there are insufficient funds set aside for the smaller projects. (These include such important interim activities as analysis of data from previous missions.)

A number of problems have attended the development of large, sophisticated missions. For example, because the Galileo mission to Jupiter is dependent on the shuttle, delays in the latter, and its associated upper stage, have caused the former to be delayed as well. The delay in Galileo caused its funding to be stretched out, and ultimately increased its costs.[1] For another example, maintaining balance within a discipline becomes a problem when, given a relatively constant space science budget, increasing outlays for one project, particularly a major one like the Space Telescope, reduces the funding for others.[2] Space science has been affected also in that the number of flight opportunities on the shuttle has been decreased and in that those missions which require a high-energy upper stage have been indefinitely postponed.

Another important aspect of the current situation is that the United States currently enjoys scientific and technological leadership in most of space science, but in certain areas, e.g., cometary research and ocean remote sensing, leadership could soon pass to the Soviets, the Europeans, and the Japanese. Failure of the United States to mount a mission to Halley's Comet puts U.S. scientists at a clear disadvantage with respect to the Europeans and the Soviets, both of whom will be flying such missions. A similar situation prevails in oceanography:

> Japan presently has an ocean satellite under development, MOS-1, scheduled for launch in 1985; it will carry all passive sensors. The European Space Agency is in the final stages of authorizing funds for ERS-1, scheduled for launch in 1986 or 1987—it will carry active and passive sensors. Canada is interested in flying a Synthetic Aperture Radar (SAR) with another country in the late 1980's.[3]

[1] See app. B.
[2] See app. C.
[3] W. Stanley Wilson, "Oceanography From Satellites?" *Oceanus*, XXIV, 3.

Chapter 3

Issues and Findings

LACK OF POLICY COMMITMENT

A major difference between the National Aeronautics and Space Administration's (NASA's) space science program and its manned program is that the latter has developed in response to national commitments to particular goals such as landing an astronaut on the Moon before 1970 or developing a reusable space shuttle; space science has not been charged with meeting particular national goals, but has proceeded in accordance with its own priorities, at a much lower level of commitment.

Because of the central importance of this issue, it is desirable to reach a clear understanding of the different levels on which the United States can (or cannot) be said to have a space policy. At one end of the scale, the 1958 National Aeronautics and Space (NAS) Act is the foundation on which the U.S. space program now rests.[1] As a kind of constitution for the conduct of space activities, the NAS act articulates the principles in accordance with which particular national policy commitments are to be framed. These policy principles include that:[2]

- peaceful uses of space are to be developed;
- U.S. preeminence in space science and applications be maintained;
- knowledge be increased;
- economic and social benefits be derived;
- civilian and military activities be separated (though they are to be coordinated so as not to duplicate one another unnecessarily;
- NASA, the civilian agency, be limited largely to research and development (R&D); and
- international cooperation be fostered.

The NAS act neither specifies national policy goals nor provides guidelines for implementing particular programs.

At the other end of the scale are particular internal policies which NASA or any other agency may institute in order to carry out its mandated duties in an orderly and successful fashion. One example of such particular policies is that NASA maintains lead-agency responsibility for space-based astronomy, and the National Science Foundation (NSF) that for ground-based astronomy.

Between these two levels is that of national policy goals. Such goals are set at the highest levels of Government; they provide a direction, define the scope, or name targets for the Nation's space activities. In addition, a policy goal defines by its wording the relative importance of the activity. The most significant aspects of these goals are that they often command bipartisan support, that they outlast any given administration, and therefore, that they serve as pledges that the Nation will support the long-term conduct of the specified space activities. At present, no national policy goals for space science exist.

Without national commitments to particular science goals, waste and instability in the space science program have been unavoidable: 1) projects being planned have been substantially changed or reordered in priority (e.g., Galileo), 2) projects under development have been deferred or canceled (e.g., the Mars Voyager mission), and 3) projects in operation have been scheduled for early termination (e.g., the Apollo Lunar Service Experiment Package, ALSEP).[4] In addition, the absence of policy goals has meant that several important questions, the answers to which determine the characteristics of the space science program the Nation actually undertakes, are decided ad hoc. These questions include:

[1] National Aeronautics and Space Act of 1958 (42 U.S.C. 2451 et seq.), as amended.

[2] For a fuller discussion of these policy principles, see: *Civilian Space Policy and Applications*, OTA-STI-177 (Washington, D.C.: Office of Technology Assesment, U.S. Congress, June 1982), pp. 35-44.

[4] Part of the reason for these difficulties is that a commitment to science is usually understood to be a commitment of funds to a "new start." More conducive to the accomplishment of good science would be a view that a policy commitment entails commitment to a *program* of investigation (i.e., a series of related missions extending beyond the time when the instruments are successfully operating to include funds for data analysis and design of future experiments). For further discussion of a program approach to science, see *"New Starts" v. "Programs."*

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- How may the goals of space science research be maintained vis-a-vis the objectives of a much larger manned space program?
- What is the proper mix of expensive, complex science projects and those that are simpler and less costly?
- How may international missions be undertaken effectively?
- How can the management of space science be improved?

The issues raised by these questions will be examined in the subsequent sections of this technical memorandum.

The key factor to be noted here is that in the absence of a national policy goal for space science, program decisions are determined by the size of the available budget. The reverse situation, in which policy determines budget, would probably be the more desirable, but neither Congress nor any recent administration has made a policy commitment strong enough to do so. If such a policy commitment were made, it would then be possible to set a base budget adequate to sustain the activities deemed essential to meeting the goals of that policy.

An advantage of adopting one or more national policy goals for space science would be resolution of the question of balance in the space science program. Traditionally, it has been thought that science as a whole progresses best when effort is rather evenly balanced among its parts. Maintenance of a balanced effort by means of an even spread of funding has, for example, been the cornerstone of NSF's support of science. Space science, however, forces a reconsideration of what balance in the program should mean, because some disciplinary areas (and the planetary sciences in particular) seem to have a higher threshold value for worthwhile missions than do others.

If a national policy commitment to a clear set of goals for U.S. space science were in place, space scientists would have a more realistic framework within which to set their priorities. Even without such a commitment, it is necessary, given NASA's limited budget, that scientists make a more thoroughgoing attempt to weigh scientific priorities against considerations of cost.

CONTINUITY, PLANNING, APPROACHES, COSTS, AND LIAISON

There are several problems in the space science program that result from causes other than the absence of policy goals. These causes include: modification of long-term planning in response to near-term crises, NASA's emphasis on "new starts," the accumulation of costs that may be unnecessary, and the need for more effective contact between the scientific community and the appropriate congressional committees and their staff. These problems are summarized in this section.

Continuity and Planning

Continuity is essential to the accomplishment of good scientific work; no scientist can respond efficiently to frequent, major perturbations. Continuity is particularly important when the Nation undertakes cooperative programs with other countries. The development of hardware and software and the training of personnel cannot be accomplished overnight. In addition, the cancellations and/or deferrals of programs (International Solar Polar Mission, Venus Orbiting Imaging Radar, Gamma Ray Observatory, Galileo, Origin of Plasmas in the Earth's Neighborhood, Upper Atmosphere Research Satellite, etc.) suggest to many young scientists, engineers, and technicians that the future of U.S. space science programs is now sufficiently uncertain that they should direct their careers elsewhere.

One step in addressing the discontinuities in the space science program would be to establish policies that would permit effective long-range planning. If such policies were in place, the program would be more stable because discontinuities would be minimized, if not eliminated. According to the workshop participants, achieving stability in the space science program, through effective implementation of NASA's long-range plans, is at least as important as raising the current level

of funding. The key term here is "effective;" NASA's long-range planning seems formally to be quite good, requiring few modifications. However, if there were a stronger national policy commitment to space science,* NASA's long-range planning would be less affected by instabilities deriving from extreme budget fluctuations** and by delays in portions of the manned program on which the science program is dependent.

Because space science projects require a decade of work from serious inception to significant funding, a good long-range plan should span 10 to 15 years. Within the general guidelines of any plan, however, flexibility must be maintained, first, because the priorities of science may change, and second, because budgets tend to fluctuate. Given that a base budget has been established as a matter of national policy, the plan could make provision for periodic adjustments resulting from those budget fluctuations. In general, the plan could be elaborated within two separate budgets, one for science per se, the other for missions, including hardware, launch, and operations. The first would establish a base level of continuing activities, all of which would be supported even in times when overall funds are strictly limited. The second would establish a set of initiatives, subject to revision in the light of scientific advances or because of changes in scientific priorities, to take advantage of unique opportunities as budget allocations allow. In particular, provision should be made that:

- a detailed subset of the plan extend over 3 to 4 budget years,
- all interested parties contribute to the formulation of the plan,*** and
- there be developed alternatives in the schedule and scope of the program that correspond to realistic alternatives in the final budgets.*

Finally, subject to full discussion and periodic review, the plan could incorporate decisions reflecting the balance to be struck among subdisciplines.

"New Starts" v. "Programs"

The current practice of designing most flight missions as independent new starts tends to emphasize the space spectaculars and to distort priorities of space science, thus reducing the efficiency with which its objectives are pursued. In many cases a more cost-effective method would be to support continuing programs, which might include small- to moderate-sized missions as part of the baseline, and to obtain new-start status only for the more expensive missions.

NASA's conduct of space science by means of spectacular, independent missions has achieved notable successes in opening new scientific domains to investigation. In addition to accomplishing much good space science, such missions are attractive to Congress and to administrations because they appeal to the public and because they add to the international prestige of the Nation.

Another characteristic of stand-alone new starts, however, is that they tend to be expensive. There is every temptation to make these missions as sophisticated as possible, rather than to design them to accomplish, say, 90 percent of the scientific objectives at 50 percent of the cost.** In times when the budget for space science is large enough to meet the major objectives of science, this method of conducting research presents few problems, but in the present era of more limited available funding, another method may be appropriate.

*Throughout this document, the notion of stronger policy commitment is to be distinguished from that of a greater funding commitment (i.e., larger appropriations); neither necessarily implies the other.

**To see that there have been extreme budget fluctuations, it suffices to consider the figures in app. A.

***It is important for all components of the space science establishment, Federal and non-Federal alike, to participate in the planning process. If all groups are invited to contribute to these discussions, those which may be adversely affected by the final outcome will have a better chance to adapt to their new constraints and will have less cause to complain. In addition, particular attention should be paid to interagency coordination. The importance of this topic warrants separate discussion, in see *International Concerns*.

*Given that budgets might vary from 5 to 10 percent above and below the planned levels, three alternative plans might be devised: one, in which the current level of effort is maintained, and one each for a 5 to 10 percent increase or decrease in the current level. If it is necessary for the budget to be cut, or possible for it to be raised, the existence of these alternative plans will facilitate making the corresponding changes in the program, with minimal wasted effort.

**To a first approximation, it is just as difficult to obtain commitment to a small mission as to a large one.

The major alternative is to conduct space science research programmatically—i.e., to emphasize the development of disciplines and continuity of operations rather than to emphasize new starts (see app. A). This approach might be realized by sets of several closely connected space missions or experiments, planned as integrated series, directed toward well-defined goals of the several subdisciplines, and supported by programmatic and budgetary continuity from inception through postmission reduction and analysis of data.

Funding Delays and Effects of Cost Uncertainties

Funding delays, wherever they arise, generate increased costs, and these, in turn, cause instabilities in program planning, leading finally to an instability in the program and the planning process.

One important aspect of program stability is sound implementation. If projects turn out to have been initially underbudgeted, or if they must be stretched out in order to accommodate budget cuts, their cost effectiveness decreases. The Galileo mission is an example where costs have increased substantially because of delays; the result is fewer missions or higher overall costs. Although current budget totals appear to compare favorably with those of the past, a larger portion of current funding in fact tends to go toward supporting unproductive work, as is the case with Galileo.*

*The labor expended in redesigning a mission for other than scientific reasons, particularly when it is done more than once, can hardly be considered productive.

The appearance of current budget totals (see app. A) is deceptive in another way: just as the Space Telescope is taking a larger portion of NASA's physics and astronomy budget, so Galileo is doing the same for the planetary science budget—a factor which makes the decrease in the overall total of the latter even more serious for other parts of the planetary program.

The Need for Adequate Discussion of Program Priorities Among Interested Participants

If they wish to take a more active role in setting national policy goals for space science, appropriate congressional committees need to have closer contacts with the space science community. Because of its scientific status, its representative character, and its relative independence, the Space Science Board (SSB) of the National Academy of Sciences could be the appropriate vehicle for improving the liaison between Congress and the community of space scientists. Especially if, as suggested in the section entitled *Management Issues*, its advisory responsibility is widened to include related activities within other agencies, SSB can present formally to NASA and informally to Congress an integrated program of space science priorities based on the process of peer review. Through annual discussions with SSB, or more frequently, if appropriate, congressional staff could, in turn, assist scientists in understanding congressional priorities and funding considerations.*

*A formal relationship could also be established between Congress and SSB. In this mode, Congress through its committees could ask SSB to carry out special studies, in which case Congress could be expected to contribute to SSB's costs. If this were done, SSB would be related to Congress as it now is to NASA: reports would not be delivered to Congress until they had been carefully reviewed and approved by the National Academy of Sciences through the mechanisms of the National Research Council. It would be desirable, however, for congressional staff to attend the nonexecutive sessions relevant to the studies, so that nothing in the final report would come as a surprise.

IMPACT OF MANNED SPACEFLIGHT—PRESENT AND FUTURE

Manned space projects arise as national political imperatives. Their total costs dwarf the science components that accompany them, and their impact on the space science program is substantial. Although scientists will learn to make good use of the shuttle, that vehicle is inappropriate and inadequate for certain kinds of research. Similarly, if a single permanent, manned space station is built, its architecture and orbital characteristics will to a large extent determine the kinds of space science research that can be done. For example, X-ray research needs a low-inclination orbit; solar terrestrial research and weather monitoring need high-inclination orbits. In general, a space station could be useful to science if: 1) a large enough research and analysis budget is set aside; 2) requirements for cleanliness and capabilities for pointing are met; and 3) access to orbits incom-

patible with the shuttle is assured (i.e., a commitment to an orbital transfer vehicle is made).

Many scientists believe that the United States should ultimately develop a permanent presence in space, centered on some type of manned space station, and that the need for such an effort will become more evident as the intentions and capabilities of other nations become clearer. In its planning for a possible space station, NASA has initiated extensive discussions with the Space Applications Board and SSB of the National Academy of Sciences to define the science and applications needs that a space station could meet. Scientists remain concerned that capabilities promised for a space station be in fact achieved, in order that situations may be avoided in which these capabilities—on which scientists have counted in planning and designing their experiments—remain merely virtual. Scientists are also concerned that cost overruns for a space station might, at least indirectly, reduce the funding available for the space science that cannot be done on a space station, or might result in a less ambitious project from which science capabilities might be excluded.*

Although most space scientists prefer to conduct experiments on unmanned flights, they will now have to tailor many of their projects to manned flights. To date, most space science experiments do not require the assistance of astronauts, whose presence adds greatly to the expense of missions. In the future, however, this situation may change. Already, the manned program has been very valuable to solar physics (e.g., in X-ray and ultraviolet photography of solar flares from Skylab) and to planetary science (e.g., in the selection of lunar samples), and it promises to be important for the life sciences. Eventually, astronauts may retrieve, repair, or refurbish scientific experiments, just as they may construct large space structures which hold promise for space research.

*Space scientists remain convinced that cost overruns on the shuttle have been a major cause of the problems now facing the space science program. See, for example, app. F.

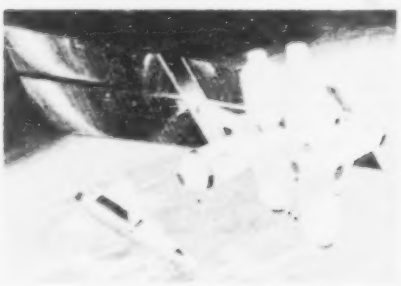

Photo credit: National Aeronautics and Space Administration

Artist's conception of future space station tended by advanced space shuttle

General Problem of Big Projects

For purposes of this discussion, a dividing line between big and small projects within NASA might be set somewhere between $100 million to $200 million.* Small projects include unmanned,

*More accurately, there are four major mission categories: 1) small (<$100 million to $200 million); 2) large ($200 million to $750 million); 3) very large ($750 million to $1,500 million); and 4) manned missions. Explorers fit into the first category. The second contains missions such as Galileo, Voyager, HEAO, Landsat, and GRO. The third contains the Viking missions, the Space Telescope, and the proposed OPEN and AXAF missions.

Photo credit: National Aeronautics and Space Administration

A 15-second far-ultraviolet exposure of the Earth, showing the extended hydrogen geocorona. This picture was taken by Apollo astronauts on the Moon

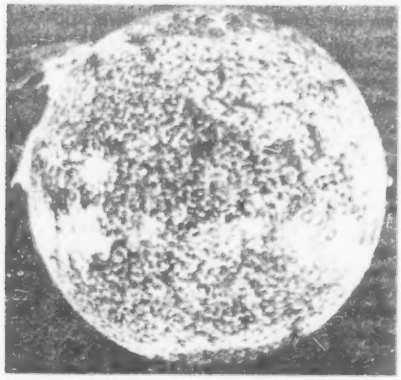

Photo credit: National Aeronautics and Space Administration

This photograph of the Sun taken Dec. 19, 1973, by astronauts aboard Skylab, shows one of the most spectacular solar flares ever recorded, spanning more than 588,000 km across the solar surface

typically scientific spacecraft in the Explorer class; big projects include all the manned efforts as well as several important science and applications missions, including Viking, Voyager, and Landsat. In practice, the large projects are divided into two categories: those, like Apollo or Space Shuttle, which respond to a national policy commitment and those, like Galileo or Voyager, which respond to the priorities of particular communities of end users. To date, no unmanned missions have fallen into the first category.

Within NASA, missions of the first type are given priority over those of the second, and those of the second tend to receive priority over small projects. The scientific community is apprehensive, on the one hand, that large manned projects will increasingly call the tune for the entire space research program, specifically that science projects will be required to use the shuttle or a new space station, and, on the other hand, that large space science projects will draw funds away from smaller ones.

There are different points of view concerning the role of big projects within NASA. One point of view, reportedly shared by all previous NASA Administrators, holds that the agency's raison d'être is its large manned programs, and that much of what the agency has been able to accomplish in space research has been based on the existence of those programs. A contrary point of view, shared by a number of scientists, holds that the Nation would have recognized the importance of basic research in space and that the space science program would have been successful regardless of the presence of large programs like Apollo or the Space Shuttle. The rationale given for this second point of view is that space science and the techniques for accomplishing it have provided and may be expected to continue to provide the basis for most of the utilitarian applications of space technology.

The Nation's past and largely successful space science effort has been conducted with both large and small projects in progress at the same time. Just as there are fundamental questions in high energy physics that cannot be answered without large particle accelerators, and questions at the frontier of astronomy that cannot be addressed without large telescopes, so there are important areas in space science that can be opened for investigation only by large, sophisticated missions.

On the other hand, small space science projects (e.g., those conducted on balloons or rockets, laboratory investigations, data analysis, and instrumentation development) are important in at least two respects: first, it is uneconomical to employ large instruments to do what small instruments can do; second, the existence of relatively many small projects provides the overall scientific context of the field, from which new ideas and concepts originate. A space science program consisting only of small projects would, over the long term, produce results of decreasing interest; one consisting only of large projects would soon be unsupportable.

NASA is aware of these arguments and, by conducting large and small projects simultaneously as much as possible, has strived to maintain a balanced space research program. With the maturation of each of the disciplines in space science, with level or declining budgets, and with other large, costly projects within NASA, it has become increasingly difficult to conduct a well-balanced space research program. Since autumn of 1981, the large-scale science projects have been par-

ticularly under attack, for the elimination of one or more of them would free substantial funds for other programs.

Another consideration is that, in a situation of more limited funding, large space science missions can be flown less often, partly because the competing needs of the several space science disciplines call for higher percentages of the space science budget, and partly because the growing sophistication of the instrumentation on these missions tends to make them more costly. Indeed, the frequency with which they are flown has decreased to the point where major groups within industry and in U.S. universities that are necessary for a successful, long-term space science program are being disbanded.

In summary, large science projects are necessary to sustain scientific progress, but tend to crowd out smaller scale projects, and, given current budget constraints, they have been mounted less often than required to maintain space science teams. In the present situation of level overall funding divided among fewer, but generally more expensive activities, an increasingly heterogeneous space science community has been forced into a mode of divisive competition for available resources. The diversity of the community, set in the context of constrained funding, makes consensus on priorities set by means of broad-based peer review especially difficult to achieve. Thus, officials at NASA, whose responsibility it is to make these decisions, face growing difficulties. A good solution to this complex set of problems is not yet evident.

Costs of Shuttle Payloads

During the past decade, the United States has spent some $20 billion for development of the space shuttle, which is the fundamental component of the Space Transportation System (STS). Advocates of this development have maintained that STS will: 1) advance the Nation's technological competence in space flight, 2) make it feasible to continue manned flight, and 3) reduce the cost of launching scientific and applications payloads (below the cost of launches on expendable unmanned launching systems), and thereby greatly expand the practical uses of space technology. The first and second of these objectives

Photo credit: National Aeronautics and Space Administration

Launch of the space shuttle Columbia

seem well served by the shuttle; the verdict on the third is not yet clear.[3] The whole question of how shuttle costs ought to be calculated is vexed. NASA's current policy is to recover from users only the marginal operating costs of shuttle flights, not total operating costs. (See app. D for a comparison of shuttle and expendable launch vehicle (ELV) costs.)

Constraints Imposed by the Shuttle

Use of the shuttle, both because of what it requires and because of what it can and cannot ac-

[3]See, for example, Daniel Deudney, "Space: The High Frontier in Perspective," Worldwatch Paper 50, The Worldwatch Institute, August 1'82: "The reusable space shuttle, first tested in 1981, was expected to accelerate the exploitation of space by reducing the cost of putting an object into orbit and allowing the repair or retrieval of orbiting satellites. However, [because of] funding delays and cost overruns it now appears that the shuttle will be only marginally cheaper than the new generation of expendable rockets." See also app. E for an analysis of shuttle economics by James A. Van Allen.

complish, has a significant impact on space science. Experiments to be conducfed on the shuttle require extensive documentation because they must all be man-rated, (i.e., certified not to endanger the crew). This requirement presents an unwelcome and inconvenient barrier to scientists, and raises costs. As more experience is gained with the shuttle, however, documentation requirements for man-rating may be eased.

The brief time of a shuttle flight presents another problem for scientific experiments designed to be conducted on the shuttle. In many investigations, a shuttle flight is scarcely long enough to provide a check-out of the equipment and provides modest results when compared with really long-term temporal and spatial coverage—often for more than 2 years—with free-flying satellites. In addition, if space science is not to be limited to those orbits accessible to the shuttle, one or more high energy upper stages or perhaps one type of ground-launched, ELV will be needed to supplement the shuttle's capabilities.

The shuttle is especially appropriate for space science missions that do not require long durations in orbit, that require a heavy payload to be placed in low Earth orbit, or that can fly in shuttle orbital inclinations. Observational astronomy and Earth observational experiments can benefit from the shuttle more readily than can other disciplines. On the other hand, the present capability of the shuttle is incompatible with the needs of some scientists (e.g., atmospheric scientists who require a polar orbit, or planetary scientists who require high-energy stages for interplanetary probes). However, with greater frequency of shuttle flights, launches into polar orbits from Vandenberg Air Force Base, and the development of an appropriate upper stage, this particular problem may diminish over time.

Concerns Regarding Military Use of the Shuttle

There is a general concern throughout the civilian community that military requirements may begin to dominate the shuttle's budgets, flights, and schedules. There is a similar concern that if a space platform is built, the military would preempt it, crowding out possible uses for science.

Recently, the U.S. General Accounting Office (GAO) has reported[4] that of the 234 shuttle flights scheduled through 1994, 114 of them (i.e., 48 percent) are dedicated to the Department of Defense (DOD); in the nearer term, 13 of the initial 44 flights through 1986 will be exclusively military. Not only will DOD be NASA's single largest customer, but also, at least through 1986, when user fees for the shuttle are to be renegotiated, NASA may be charging DOD substantially less per flight than it charges civilian users—$12.2 million as opposed to $18 million, a discount of 32 percent. In addition, it seems likely that NASA will be doing substantially more work for the military, and that the Jet Propulsion Laboratory, which has been heavily involved with NASA's planetary science program, may return, for the most part, to its earlier support role for the military.[5]

[4] "NASA Must Reconsider Operations Pricing Policy to Compensate for Cost Growth on the Space Transportation System," a Report to the Congress by the Comptroller General, MASAD-82-15 (Washington, D.C.: U.S. General Accounting Office, Feb. 23, 1982).
[5] *The Washington Post*, June 5, 1982.

MIX OF SCIENCE EFFORTS

Mission Complexity

Over the years in which the United States has been conducting space science, a broad range of mission types has been flown—from relatively simple experiment packages carried by sounding rockets and high-altitude balloons, to the highly complex Voyager flybys of Jupiter and Saturn. Now that funds to support space science have, overall, been on the decline since 1974 (see app. C), it has become necessary to make certain difficult choices as to which future missions, and even which types of future missions, are to be supported.

As space science matures, missions tend to grow more complex and expensive. As missions grow more costly, fewer can be flown, given a constant or decreasing level of funding; but as flight opportunities are cut back, there is a tendency to make the remaining missions more complex (and, usually, more expensive). Some program officers at NASA believe that the era of small-scale missions is mostly passed—that to obtain scientifically useful results now requires sophisticated (and

Photo credit: National Aeronautics and Space Administration

Artist's conception of the descent of the Galileo probe into the atmosphere of Jupiter

costly) missions. It has become more and more difficult to mount small-scale missions, with the consequence that fewer sustaining activities are available between major flight opportunities.*

In view of the difficulty of planning and executing a balance of large- and small-scale missions in planetary science, NASA has established the Solar System Exploration Committee (SSEC). The charge of SSEC is to recommend to NASA an ordered, affordable program of exploration of the solar system.

*Two committees of SSB—the Committee on Space Astronomy and Astrophysics, and the Committee on Solar and Space Physics—are currently examining these issues.

There is disagreement about whether large or small missions are the more cost effective, and a detailed analysis of this question is beyond the scope of this study.* Similarly, the question of whether the Nation's broad technological base would be strengthened by a policy of funding more small missions is difficult to resolve. Basic agreement, however, seems to exist on the position that a range of missions makes the most scientific sense. Not only will the small missions pro-

*Often a debate about cost effectiveness degenerates into a dispute about costs. It is tautological to assert that large missions cost more than small ones; the real question involves the amount of science returned per dollar of outlay. (The probability that quality of science differs from quantity of science is another complicating factor.) The absolute increase in launch costs, which translates into an increase as a proportion of total mission cost, has become a dominant factor in such calculations.

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vide a continuous level-of-effort when budgets are low, but these types of small expenditures, including the funding for laboratory work, will lead to interesting and promising new laboratory techniques and other new instrumental approaches.

If NASA were to revive small-scale scientific missions, some sort of safeguard would be necessary to allow at least some of them to *remain* small. One possibility would be to adopt some version of the strategy employed by the Department of Defense (DOD). The U.S. Air Force has been designated as the service responsible for coordinating much of the unclassified space research for DOD, and it does so through the Space Test Program (STP). A scientist who is interested in flying an experiment on an STP mission submits a proposal without knowing to which mission it will be assigned. Both university-based scientists and those at Government labs may compete for space on a mission.

Experiments are selected for utility and relevance to the DOD mission. Once the experiments have been ranked within each DOD lab, STP selects a compatible set of lab and university-based experiments for flight on a mission for which one or more DOD experiments have the top priority. There is an average of six or seven experiments per flight, together with the experiment(s) for which the flight was chosen. As of spring 1982 there have been 32 STP flights. Currently, the average is one flight per year. The cost for an STP flight is comparable to that of an early-day Explorer mission.

Scientists who have experience with STP cite several advantages that it provides:

- minimal documentation;
- minimal oversight and review procedures;
- emphasis on low-cost missions;
- willingness to stand by decisions, with no rescoping;
- willingness to accept experiments with a relatively high risk of failure; and
- possibility of short turnaround times for some types of experiments.

There are, however, some generally perceived disadvantages. These include:

- orientation toward narrowly conceived missions;
- inadequate support for postflight data analysis;
- uncertainty of launch time and possibility of long waits in the queue;
- poor cross-checking of experiments for payload compatibility; and
- a failure rate higher than that of NASA.

For the needs of space science, the general negative feature of STP is that it supports isolated missions rather than basic research programs.

Some features of STP appear to be attractive for the support of small-scale missions; some of its procedures might be adopted by NASA in cases where they would be appropriate. Another possibility would be for NASA actively to promote, through wider publication and support, the flight of experiments in which it is interested on STP missions. STP offers some segments of the scientific community an alternate way to fly an experiment at low cost and with few restrictions.

Funding Allocation for Data Analysis

Compared with the costs of the actual mission (including launch vehicle, instrumentation, mission operations, and support facilities and personnel), the cost of postmission data reduction and analysis is minor. Even so, according to recent independent reports of SSB and GAO, the funding set aside for data analysis is inadequate.[a]

NASA's emphasis on supporting new starts has tended to concentrate attention on hardware and operations, rather than on the total scientific project. Consequently, proper attention to the problem of data analysis has not been given beyond that required for the major, relatively easily achieved initial results of the experiment. There is, however, more science to be gained by allocating an additional small percentage of the total cost of the mission to further data analysis. Continued examination of the data can still yield im-

[a]According to GAO, "the Congress should examine the adequacy of NASA's allocation of resources between gathering space science data and analyzing it. Greater emphasis is needed during the data analysis phase of a program to obtain the maximum scientific benefit from the data obtained." ("More Emphasis Needed on Data Analysis Phase of Space Science Programs," a Report to the Congress by the Comptroller General; PSAD-77-114; June 27, 1977). See also the CODMAC report of SSB ("Data Management and Computation, Volume 1: Issues and Recommendations," National Adademy Press, 1982).

portant scientific advances as new techniques for analysis are developed, existing techniques are refined, and increased understanding of the underlying physical processes is acquired.

Postmission data analysis is often the lifeblood of university space research groups. If NASA places more emphasis on this activity, these groups will be better protected in times of more limited budgets; data analysis is a type of activity that can be conducted with success, regardless of the level of the overall budget. At present, however, follow-on data analysis for the lunar and Martian missions, as well as for those of several subdisciplines (e.g., X-ray astronomy), is funded below the level at which the activity can remain viable. If all scientific activity is not to cease in those areas of research which will have no missions for the foreseeable future, then a base level of funding for data analysis must be maintained.

In addition, there is a need for data from past missions to be correlated over a long time sequence in order to corroborate the findings of independent missions and/or experiments, as well as to facilitate syntheses unifying results from related fields of science. Past results are often the key to understanding in the fields of solar physics, solar-terrestrial relations, and atmospheric physics, all of which require that data obtained over many years be compared in order to understand the basic processes in the Sun and in the Earth's weather and, in particular, to discover cyclic phenomena.

Archiving of Data

Whether or not data returned from space missions should be archived depends on several factors, including that of costs v. benefits. Because space missions are very costly, and the data returned from them correspondingly valuable, data should be archived if they are likely to be lost, if the cost to repeat the experiment is sufficiently large, if a long time base is crucial for the success of the project, or if the data might be unavailable when required. Too often, however, data may have been archived as an alternative to timely analysis.

One technological development that may go far toward solving the problems of data archiving is the new laser-read video disk. All the data returned from the Voyager missions to Jupiter and Saturn could be stored on disk and made widely available to scientists for a few hundred dollars. An investment in technology will still be needed to realize this possibility, and it will still be necessary for a calibration program to be included on each disk in order to make the data most usable to other researchers.

INTERNATIONAL CONCERNS

International cooperation promises scientific, cultural, economic, and social benefits to all participants. Over the long term, the prospects for international cooperation in space science ventures look very good. In general, it seems clear that missions that would be too expensive for the United States to mount alone could be undertaken with international support. The space programs of the Europeans and the Japanese have now sufficiently matured to permit them to become substantial partners in joint missions. While the current international situation tends to minimize East-West interactions in high-technology fields, the Soviet Union is quite active in space research activities, and it would be to the Nation's advantage to cooperate in some areas where the U.S.S.R. is clearly the leader--e.g., in the life sciences. In the past, international science projects have been one of the most effective means of making contacts across cultural and political barriers.

In the short term, however, prospects for major cooperative efforts are not so bright. Cancellation of the U.S. spacecraft in the International Solar Polar Mission argues that the United States and the U.S.S.R. are unreliable partners. If Spacelab-6 (to which Canada has already committed substantial funds) is also disapproved, foreign governments will be even less likely to agree to international ventures with the United

States. In any case, there seems to be little possibility for cost sharing on the missions in the immediate future, for most of them are already planned and do not include foreign partners. A more feasible form of cooperation for the near term is that of coordinated spacecraft launches, such as the International Sun-Earth Explorer missions, where each spacecraft is fully prepared by a single nation; in such cases, the scientific benefits derive from the sharing of data. However, the decision not to fly an appropriately designed mission of this sort to Halley's Comet, in coordination with the Giotto spacecraft of the European Space Agency (ESA), represents another lost opportunity for international cooperation.

In general, a more effective mode of cooperation must be devised that will allow two or more nations jointly to plan and execute space missions with minimal difficulties. There are two particular concerns that should be addressed. One is that commitments which the United States makes to international ventures should, if at all possible, be kept. Nothing will more effectively prevent future joint missions than a U.S. record of broken agreements. Cancellations of U.S. commitments to international space ventures may be necessary for budgetary reasons, but such cancellations indicate uncoordinated budget planning and the lack of concerted, bipartisan support for space exploration. It would seem fruitless to urge that, in order to avoid such cancellations in the future, commitments to international missions should be made at higher levels of authority, for some of the international commitments on which the United States has reneged were made by Congress. Nevertheless, it would be desirable to devise some means of assuring that U.S. commitments are honored.

The second concern is that, whereas NASA has allowed foreign experiments to be proposed for inclusion in U.S. missions (e.g., 20 percent of the instruments on the Space Telescope are Euro-

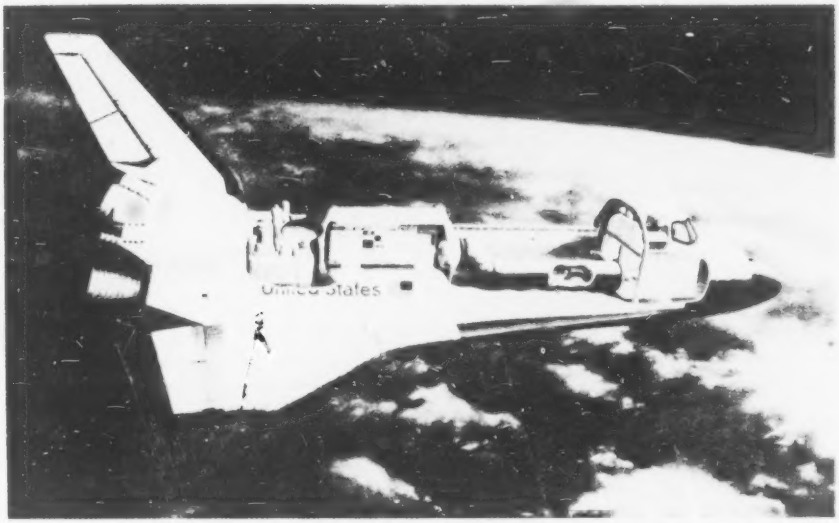

Photo credit: National Aeronautics and Space Administration

Artist's conception of Spacelab in the cargo bay of the orbiting space shuttle

pean), foreign organizations have generally been opposed to including U.S. experiments on their spacecraft. Now that foreign programs have in important respects become competitive with those of the United States, there is less need for them to protect their missions from possible dominance by U.S. teams of experimenters. In response to U.S. pressure for an appropriate quid pro quo in order to redress this imbalance, ESA, at the urging of the Space Science Committee of the European Science Foundation, has recently begun to formulate a new policy to address this problem.

From the U.S. point of view, increased participation in foreign missions is desirable. First, it obviously costs less for a U.S. team of scientists to pay the incremental costs of participating in a mission whose major costs (for design of the mission, for the launch vehicle, and for various support services) are borne by a foreign agency, than for the United States to develop and fly a comparable mission. Second, U.S. scientists find the cross-fertilization of ideas which results from participating in foreign missions to be very valuable. Nevertheless, if the level of U.S. participation in foreign missions does increase, the Nation should be prepared to provide the travel and other mission support costs that will be necessary to assure the success of that participation.

One difficulty for international cooperation in science surfaces when foreign experimenters participate in U.S. missions, for acceptance of a foreign proposal in a given subdiscipline necessarily reduces the support for U.S. teams competing in the same subdiscipline. Another problem is that NASA does not have well-understood and uniform procedures for funding U.S. co-investigators on European missions.

In summary, the prospects for international cooperation on large-scale projects, which the United States would find it difficult to fund alone, appear to be promising. Before an international venture is begun, however, it should be assured that all partners will gain by the cooperation, that it can be carried out with the backing of all participants throughout the lifetime of the project, and that the additional administrative costs that will be incurred are acceptable.

MANAGEMENT ISSUES

Management Alternatives

To date, most of the support for space science research has come from NASA, though DOD has funded much classified activity as well as the relatively small STP effort, and NSF supports work in ground-based astronomy and some data analysis and theoretical work in solar-terrestrial space physics. As space science has developed into well-defined disciplines and subdisciplines, requirements for flights to further their research programs have multiplied. Because of the high cost of its scientific missions relative to the cost of related science projects within DOD or NSF, NASA has a greater problem as it considers whether its missions will be supported by Congress and be appealing to the public.

It has been suggested that NASA should place more responsibility for space science experiments in the hands of principal investigators and to assign responsibility for future space science operations to organizations like the Space Telescope Science Institute (STScI). Another more radical suggestion has been to establish a separate agency, with a structure parallel to that of NSF, whose responsibility would be to support large, more costly, scientific enterprises such as space science research and high-energy physics. The general rationale for these suggestions is that NASA is chartered as an R&D agency, not an operations agency, and that the orderly progress of science requires commitment to continuing operation of scientific facilities. Both of these suggestions require comment.

Although there are good individual scientist-managers, not all scientists are good managers. As long as the science is not costly, and risks can be taken, there is considerable advantage in diversifying managerial responsibility. However, when costly, large projects are undertaken, the Government will generally institute procedures to make

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success more certain. These procedures lead to more oversight and tend to separate the scientist from his experiment.

The growth of "big science" has led to the establishment of national centers in astronomy, of which STScI is one example. Patterned after its successful ground-based counterparts, STScI is an example where managerial responsibility has been placed in the hands of the space science community. NASA set up STScI at the urging of the scientific community, although NASA's success in managing the International Ultraviolet Explorer indicated that it could have managed the Space Telescope quite effectively. In any case, STScI promises to satisfy the desires of the space scientists to have a more active management role in space research than they have had in the past.

At first sight, the establishment of a separate agency to support large scientific enterprises appears to have merit. As noted above, large projects require a different type of organizational management and more personnel than do small projects. Although concentration in a single agency would group large science projects, it might later destroy much of the internal balance and coordination between large and small science that currently exists within NASA and the Department of Energy (DOE). The new agency could easily become a target for budget cuts on the premise that a small percentage cut would still permit the science to be done, but would be the source of significant amounts of funds.

Distribution of Talent and Resources

So far, the space research programs conducted within NASA, at universities, and in industry have been rather evenly supported. The U.S. space science effort is truly a national program, and the distribution of resources and capabilities throughout the country has resulted in a reasonable balance. If, however, budgets for space science research remain constrained, then the possibility of an imbalance in the distribution of talent becomes greater because university and industry teams increasingly will have to be disbanded. It is important that a reasonable balance be maintained: healthy competition among researchers within NASA, at universities, and in industry has produced and will continue to produce the best science. Each leg of this triad has particular strengths, requirements, and/or responsibilities:

- Many of the new ideas for research originate within universities; in addition, the independence of university teams is vital to the process of correcting imbalances in the program if they should occur.
- NASA teams need sufficient work to maintain a reasonable level of competence because they manage the projects and provide valuable firsthand experience necessary for successful missions.
- As builders of most of the complex spacecraft systems, industry teams are crucial to the survival of an experimental space science. It is already the case that much of the complicated hardware for sophisticated missions cannot be built except with the expertise to be found in industry. There are too few civilian space missions to provide substantial profits for any company, but industry desires to participate in the civilian program because of the positive influence of space research activity on recruiting and retention of staff and on corporate image.

A further problem resulting from recent budget cuts is that, in order to retain key technical personnel, NASA may be assigning them to relatively unproductive oversight roles. This may lead not only to further loss of key personnel, but also to an overassignment of oversight tasks to the people who remain, even though there are fewer programs to administer. However understandable this response to a difficult budgetary situation may be, it is wasteful of resources, and in the long run, it may be detrimental to the morale of good scientists and engineers who would prefer to work in a more strictly scientific capacity.

Toward a More Effective Program

With time, the boundaries between space- and ground-based astronomy are becoming less well defined. The division of Federal funding wherein NASA has the lead agency responsibility for space-based astronomy and NSF that for ground-based astronomy is becoming arbitrary, for scien-

tists increasingly need to conduct both types of research in the ordinary course of their studies. As a result, it has been suggested that NSF should assume a larger share of postmission analysis of space-derived data and that NASA should fund a larger share of ground-based research that is of interest and importance to its overall mission. If this course is to be taken, the Office of Management and Budget (OMB) could assume the responsibility for assuring that the balance of funding available to these two agencies would allow a more effective partnership to develop in the Federal funding for space- and ground-based astronomy than that which currently exists.

A similar problem has been indicated by the Astronomy Survey Committee report of the National Academy of Sciences,[7] namely that the support for ground-based astronomy provided by NSF is not keeping pace with the support for space-based astronomy provided by NASA. In order to correct this imbalance, $40 million (in 1982 dollars) would have to be added to the NSF astronomy budget. The Solar-Terrestrial Physics report of the National Academy of Sciences also shows a relative lack of support for ground-based activities. In general, whereas at least the physics and astronomy portion of NASA's space science budget has continued to increase in recent years, NSF has been unable to make any new major capital expenditure decisions in astronomy for over 12 years.

Scientists generally do not believe that existing coordinating mechanisms are very effective. They do not see evidence that coordination is occurring at the higher levels of the agencies; some of them doubt that it occurs sufficiently at lower levels. One widespread opinion holds that OMB or the Office of Science and Technology Policy should take a more active role in interagency coordination, if only to set up a formal cross-agency advisory mechanism.

Some type of cross-agency advisory mechanism might be useful, for example, in resolving potential jurisdictional disputes and coordinating situations where one agency may wish to assume new responsibilities, to relinquish previous ones, or to exchange some of its current ones for others belonging to another agency. If an effective mechanism of this kind had been in place, the recent budgetary uncertainties involving the responsibility for funding the Infrared Telescope Facility in Hawaii might have been averted.

Another means of addressing the problem of interagency coordination would be to broaden the responsibilities of SSB to include oversight of NSF's activities in solar-terrestrial physics, astronomy, and some atmospheric research, as well as space-related activities of other agencies. As the major existing scientific advisory body for space research, SSB presents recommendations only to NASA. If, however, the purview of SSB were broadened, then its recommendations to NASA would be more likely to be based on considerations of disciplinary continuity across agency boundaries. Such continuity would help to ensure a more balanced Federal program in space science.*

In addition, it may be desirable to broaden the charter of SSB in another direction, namely, to give it the responsibility for combining priorities of space science with considerations of cost. If this is done, several considerations must be kept in mind. First, SSB, by virtue of its role within the National Academy of Sciences, operates in conjunction with an extensive process of peer review, and, hence, cannot do short-term problem-solving. Second, the space science community is quite heterogeneous (as is SSB itself); space science, properly speaking, covers a broad range of disciplines, each of which has its own set of

[7] George B. Field, report of the Astronomy Survey Committee, *Astronomy and Astrophysics for the 1980's* (Washington, D.C.: National Academy of Sciences, 1982). It should be noted, however, that this report does not treat the entire range of space science disciplines.

*On the other side it must be said that NSF's Astronomy Activity Committee already provides guidance in the area of astronomy and takes the space science activities into account. The National Academy of Sciences has found it necessary to maintain separate committees for space physics and solar terrestrial research, even though they address the same subject matter, because the modes of operation for space- and ground-based research are rather different.

In audition, such broadening of SSB's responsibilities could make it into an unwieldy bureaucracy. In each subject area in which this were done, the relevant committee of SSB would have to assume additional responsibilities, and SSB itself would have to assume more of an oversight role and less of a coordinating role. All of this would be possible only if quite a number of different offices in several different agencies consented to be advised in this manner.

priorities. Third, as contrasted, for example, with the organization of high energy physics into three or four cost centers, space science has many cost centers; it is big science, but it is not so heavily concentrated. For these reasons, SSB cannot be expected to function in the same way as does the High Energy Physics Advisory Panel (HEPAP), a scientific advisory panel of the Department of Energy.*

The heterogeneity of space science complicates the choice of priorities. Given NASA's division of space science into:

1. physics and astronomy,
2. planetary sciences, and
3. life sciences,

and assuming, further, that in each of these divisions subsets of SSB can meaningfully rank potential projects, it is nevertheless true that the assignment of a single absolute priority for all of space science from among the top ranked projects in each division is *not* a scientific decision. Such a decision is essentially political, based on considerations of what Congress is likely to support or what is needed to maintain balance among the disciplines. Space scientists are not notably more qualified to make such a political decision than is any other community.

An essential element in making this situation more tractable is to make a clear separation between the activities that are purely scientific and those that are, more strictly, engineering. In the past, the funds for the latter have far exceeded the funds for the former, and each division of science within NASA has had to pay for its missions out of its own budget. For reasons detailed earlier, big science missions—i.e., the engineering activities (hardware development, launch costs, and mission operations)—tend to consume the resources for small science—i.e., the continuing activities that are scientifically significant (including data analysis, theory, experiment design, and perhaps small to moderate missions for which hardware costs do not entirely dominate). If these budgets were separated, then SSB could very well make recommendations for setting the level of the nonmission budget, which would support the continuing science efforts of each of the space science divisions.

The level of the hardware budget, because it would have a strong political component, would be much more complicated to set. In general, because there would be a series of missions, each dedicated to one or more disciplines or subdisciplines, the level of this budget would vary rather widely, depending on the point of the mission cycle. SSB could function with respect to this budget much as it does now; i.e., it could continue to make recommendations for major missions corresponding to projected increases in available funding.

The current crisis in space science might well be an opportunity for SSB to take stock of the details of the problems indicated in this report. There is, for example, no clear accounting of the numbers of people engaged in space science, or of their distribution; data concerning the precise effects of reduced or level funding on research groups are still anecdotal. Without this information, the present health of space science research in the United States cannot be precisely assessed, nor can its future needs be predicted. This information would be especially useful for determining what an optimal base budget for space science would be.

*Overall, the HEPAP model is not a good one for SSB. High-energy physics is a rather narrowly defined scientific area with a small range of potential initiatives that have been well studied and costed. SSB and its committees, on the other hand, deal with areas in which costs are usually vaguely defined, although they make use of whatever cost information is available.

Chapter 4

The Importance of Doing Space Science

INTRODUCTION

Over the past 300 years, accelerating advances in scientific theory and practice have aided man in remaking the world. As scientific descriptions of our surroundings become more detailed, the practical consequences of applying scientific results and techniques to the problems of everyday life become more far-reaching. As the effects of science move out of the theoretician's study and the experimenter's laboratory, it is important to reflect on the reasons for undertaking science at all. It is not in the province of this report to justify the national effort in science, but it is nevertheless appropriate to discuss the importance of the space science program as a component of all Federal expenditures. Indeed, much of the rationale for doing space science is a corollary for doing science in general.

Space science is an undertaking that satisfies the visionary and exploratory needs of the human race. "In the future, as in the past, our freedom, independence and national well-being will be tied to new achievements, new discoveries and pushing back frontiers."[1] It is a cultural as well as a scientific activity that seeks to understand the Earth's place in the solar system, the solar system's place in the Milky Way Galaxy, and our Galaxy's place in the Universe. In assisting man to gain a better understanding of his place in his surroundings, space science also explores the fine structure of the universe in the form of samples, either examined in situ or returned for study on Earth.

At the bottom of the Earth's atmosphere, our ability to sense the universe is restricted to the visible and radio portions of the electromagnetic spectrum, but our extended ability to observe from above the atmosphere by means of instruments aboard spacecraft has widened our scientific vista enormously, and has permitted observations to be made of celestial objects that could not have been made in any other way. We are now truly viewing the universe through a set of multispectral eyes.

[1]President Ronald Reagan, "State of Space" speech, July 4, 1982.

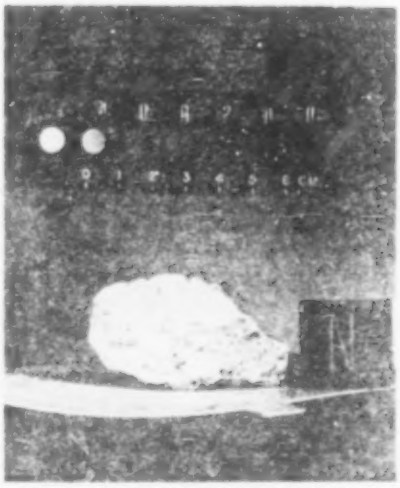


Photo credit: National Aeronautics and Space Administration

A lunar sample from Apollo 14 pictured in the Lunar Receiving Laboratory at the Manned Spaceflight Center, Houston, Tex.

Astronomy is only one of the fields of science of which instruments aboard spacecraft have revolutionized our understanding. Others include the physics and chemistry of the Sun; energetic particles; the interplanetary medium; and the planetary sciences, whose purview properly includes Earth, as well as the Moon, the other planets and their satellites, and comets and asteroids. These fields have immediate importance for life on Earth. In fact, solar terrestrial physics and the planetary sciences as conducted from space have provided the basis for many of the important utilitarian applications for space technology—communications, navigation, meteorology, atmospheric physics.

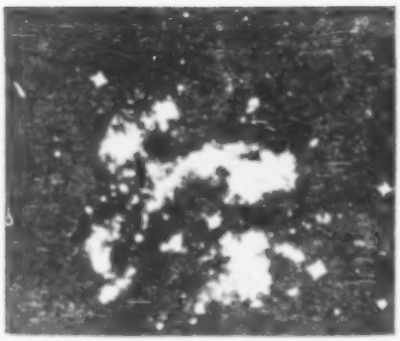


Photo credit: National Aeronautics and Space Administration

A far-ultraviolet photograph of the Large Magellanic Cloud, obtained from the lunar surface by Apollo 16 astronaut John Young, using the Naval Research Laboratory Far-Ultraviolet Camera/Spectrograph

Photo credit: National Aeronautics and Space Administration

Active volcanoes on Jupiter's dynamic moon "Io"

EXPENSE OF SPACE SCIENCE AND THE ROLE OF PUBLIC SUPPORT

Increasingly, there are those who believe that the pursuit of expensive science solely for the sake of understanding, particularly in the face of other urgent problems facing mankind, may not be defensible. Because an expensive science project is a social product that depends on the common labor of many scientists, and because tax money must be allocated to support such an activity, the decision to pursue an expensive project and to allocate resources to it among competing alternatives necessarily entails political oversight.

More than ever before, a successful scientific career now depends on the support of public and private institutions. The days when individuals of independent means could make fundamental advances in science have mostly passed. The expense of pursuing fundamental research, particularly in the areas of so-called big science (e.g., high-energy physics, astronomy conducted with large telescopes, or space science), places these activities beyond the financial means of individuals. The costs of adequate scientific instrumentation are, for the most part, not borne by those who are to use them, but by Federal, State, and private laboratories—and ultimately by society as a whole. Thus, there is a kind of social contract between scientists and society, in which the pursuit of knowledge is exchanged for economic support.

Although the results of science have become part of our common heritage, the practice of science is becoming more and more a cooperative enterprise. Even though the individual genius will always be important in the process of scientific discovery, especially in purely theoretical work and in the practice of small-scale science, teams of scientists engaged in large-scale research projects are now quite common.

If society agrees to support science, the problem of just how that support should be apportioned remains complex. First, the very progress of science often leads to the need for more powerful instrumentation, especially in space science. As our understanding becomes more detailed, additional subdisciplines are founded, and each of them requires continued public support if it is to advance further. At the same time, other subdisciplines may be terminated, either because they reach a natural close or because they become too expensive to pursue further. In general, however, a situation where overall funding does not increase requires that some projects be delayed, stretched-out, or dropped, if others are to be supported.

Second, it is not possible to predict which scientific research programs will lead to improvement in the quality of human life. Applied science and engineering are undertaken with a view to producing relatively near-term benefits, but their productivity will soon become exhausted if a broad-scale program of basic research is not sustained.

It is important in this context to distinguish between *further* or *continued* research at a more or less constant level of funding and *expanded* research at a higher level of funding. In this report, OTA examines what value space science research has had in the past and is likely to have in the future, and what difficulties have arisen in maintaining a research effort at more or less constant overall funding levels; OTA has not considered the desirability of increasing funding levels for space science.

EARTH AND THE PLANETARY SCIENCES

The pursuit of planetary science has been of substantial importance to many of the geosciences, including geology, geochemistry, geophysics, geodesy, cartography, and photogrammetry. Exploration of other planets has returned results fundamental to understanding the evolution of Earth. These results derive, in large part, from the study of the crustal features and inferences about the interior of terrestrial (i.e., Earth-like) planetary bodies, including Mercury, Venus, Mars, and the satellites of Jupiter and Saturn.

The two principal drivers of planetary evolution are tectonism and vulcanism. Tectonism, the

Photo credit: National Aeronautics and Space Administration

Earth as a planet: the weather satellite GOES EAST shows two hurricanes bracketing Mexico, on Aug. 8, 1980

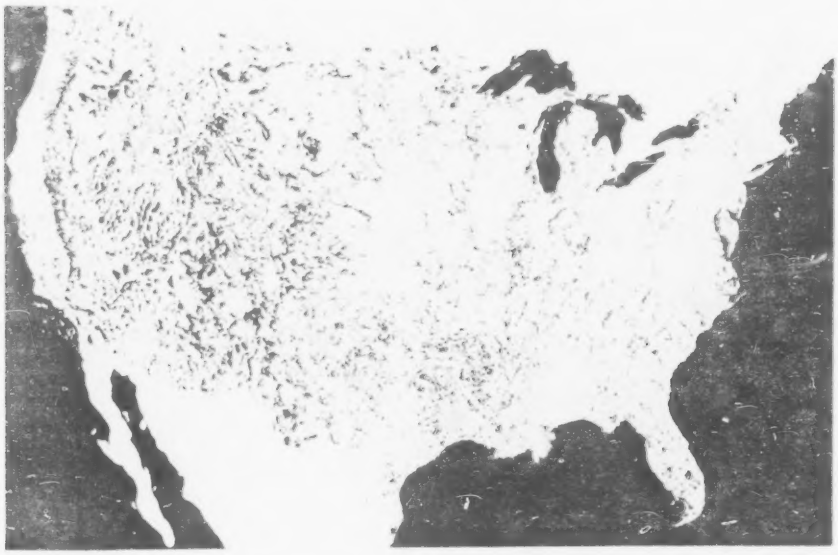


Photo credit: National Aeronautics and Space Administration

A giant photo map of the contiguous 48 States of the United States, the first ever assembled from satellite images. The images were produced by the Multispectral Scanner aboard Landsat I (formerly ERTS-1) between July 25 and Oct. 31, 1972

processes that determine how the crusts of planets deform and buckle, is important to understand for purposes of predicting and giving early warning of earthquakes; research into vulcanism, the processes whereby molten portions of a planet's interior emerge onto its surface (either on the seabed or on land, in the case of Earth), is a subject of practical importance because further understanding may eventually lead to prediction of volcanic eruptions.

Both earthquakes and volcanic eruptions remain major hazards in many parts of the world. The thorough devastation resulting from the recent eruption of Mt. St. Helen's in Washington State and the great loss of life in recent earthquakes in Italy and Central America attest to the power of these processes and their consequences for human life. Planetary science is providing revolutionary insight into these processes. The hyperactive vulcanism on the Jovian satellite Io, for example, follows an entirely different pattern from that of the Earth; study of these differences may be the key to understanding how volcanic processes work.

Planetary science, by furthering our understanding of the processes whereby mineral deposits are formed, may provide unexpected assistance in evaluating, seeking, and discovering these resources on Earth. Extensive research on Earth has revealed that mineral deposits are unevenly distributed; a fundamental problem in plate tectonics—the theory of how the continental land masses slowly move over the Earth's surface—is to explain the peculiar distribution of these deposits. Many of them are very ancient, formed when Earth was more like the Moon, Mars, or Venus;

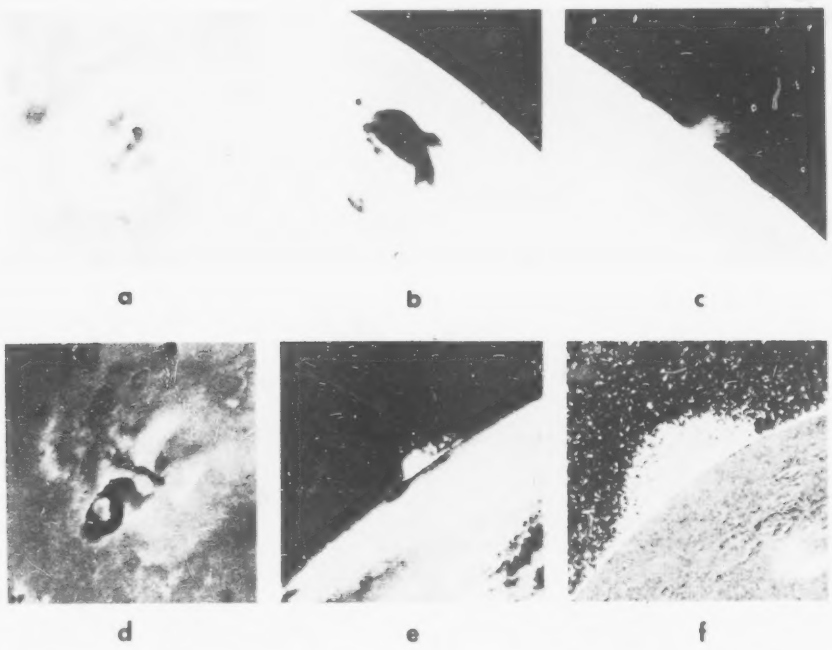


Photo credit: National Aeronautics and Space Administration

Successive images of volcanic plumes on Io, taken from the Voyager I spacecraft

some of these are no longer being formed; others are still being produced, by a combination of crustal movements and volcanic activity. Comparative studies of other terrestrial bodies are assisting in the resolution of these issues.

In many respects, Venus and Earth are twins, but they have taken radically different evolutionary paths. Scientists now think that Earth owes its particular course of development to the early formation of life. Life forms in the early ocean are thought to have pulled carbon dioxide out of the atmosphere and laid it down in limestone. Decreasing the level of carbon dioxide prevented the runaway greenhouse effect that characterizes the atmosphere of Venus, and this in turn preserved Earth's oceans. Recent evidence from Venus indicates that it once had oceans, too. Presumably, however, life did not appear at all there, or it did not become sufficiently widespread to remove much carbon dioxide.

The oceans are not a mere secondary feature of the Earth's surface; they permit continued evolution of its crust. Ocean water cools molten basalt emerging from the midocean ridges, thus making the basalt dense enough so that the continental plates can "float" above it. Without this oceanic cooling of basalt, the continents would freeze in place, as they have on Venus. In this view, sea floor spreading and plate tectonic motion, made possible by the presence of the oceans, provide

the present dynamic control of Earth's evolution. Thus, the presence of life and the presence of the oceans make Earth unique, at least in our star system. Life and the oceans each owes their preservation to the other, and the oceans control the way Earth's crust forms and therefore, indirectly, the course of evolution of living things. Without a study of Venus—an opposite case, where some particular differences have made all the difference—it is unlikely that our understanding of Earth's evolution would have progressed as far as it has.

Planetary science, therefore, has enlarged and deepened our understanding of the fundamental processes molding the Earth. In addition, it has given evidence both of what kinds of results might be expected if the balance of Earth's system were disturbed, and of how a relatively small change could drive the whole system into a dry, dead end.

FORMATION OF THE OZONE LAYER

The monitoring of ozone is one example of a practical activity growing out of space science. Ozone is a small, but important constituent of the Earth's atmosphere: too little of it in the stratosphere allows dangerous levels of ultraviolet radiation to reach the Earth's surface; too much of it near the Earth's surface has more immediate deleterious effects on human health. The level of ozone in the stratosphere can be altered both through increased technological activity, which causes relatively slow changes, and through alterations in the level of solar ultraviolet radiation, which causes more rapid fluctuations. Whereas increased technological activity tends to add compounds to the atmosphere which decrease the stratospheric ozone, solar ultraviolet radiation produces additional ozone. The mechanisms by which stratospheric ozone is formed and maintained are still not thoroughly understood, and space research systems are being used not only to monitor ozone but to measure related parameters which are critical to increasing our knowledge.

SOLAR PARTICLE EMISSIONS

Space research systems are also useful for measuring the level at which high-energy protons, emitted from solar flares, bombard the Earth's atmosphere, particularly at high latitudes. Instruments aboard spacecraft can detect the emission of these particles early enough so that the routes of aircraft flying over the polar caps may be changed or manned satellites may take appropriate precautions. To perform well, these warning systems must be sufficiently accurate to differentiate between flares that have a major effect and those that have only minor effects. The flare signatures that will provide this separation are not well defined, and only further basic research from space vehicles will provide the answers.

WEATHER AND CLIMATE

Another example of the practical effects of space science is the observation of the Earth's climate and weather. The Earth's weather and secular or cyclic changes in its climatic conditions have a significant impact on commercial activity. Accurate weather predictions are very useful for a variety of purposes, and accurate climatic forecasts could be of great strategic value—in predicting energy consumption requirements, for example. Accurate predictions depend on a substantial monitoring system in which satellites play a major role. If these satellites are to succeed in their missions, they must monitor the most predictive sets of parameters, and their downward-looking

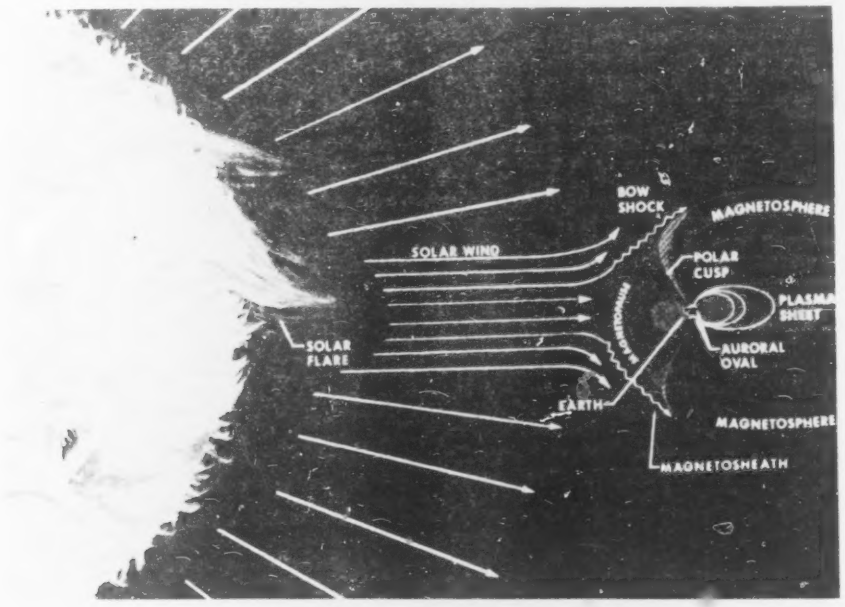


Photo credit: National Aeronautics and Space Administration

Sun-Earth radiation environment

systems must measure cloud cover, infrared and visible radiation, temperature, and the changes in these parameters. Because the relative reliability of these parameters is still under investigation, there is need for a continuing basic research partnership in which observations made from space and studies made from the ground are correlated, the parameters most critical over long time sequences are identified, and the largest available computers are employed—if there is a determination that the national interest is well served by more accurate weather predictions and climate monitoring.

Prediction of the Earth's weather presents an extremely complicated problem. Weather prediction is still in its infancy, and progress to date has been dependent on an increasingly sophisticated sensing system, combined with elaborate computer analysis. Space scientists are gaining further insight into how planetary atmospheres originate, circulate and evolve, principally because of recent space research on the atmospheres of other planets (Venus, Mars, Jupiter, and Saturn). This insight promises to remove some of the uncertainty in our knowledge of the circulation patterns of the Earth's atmosphere.

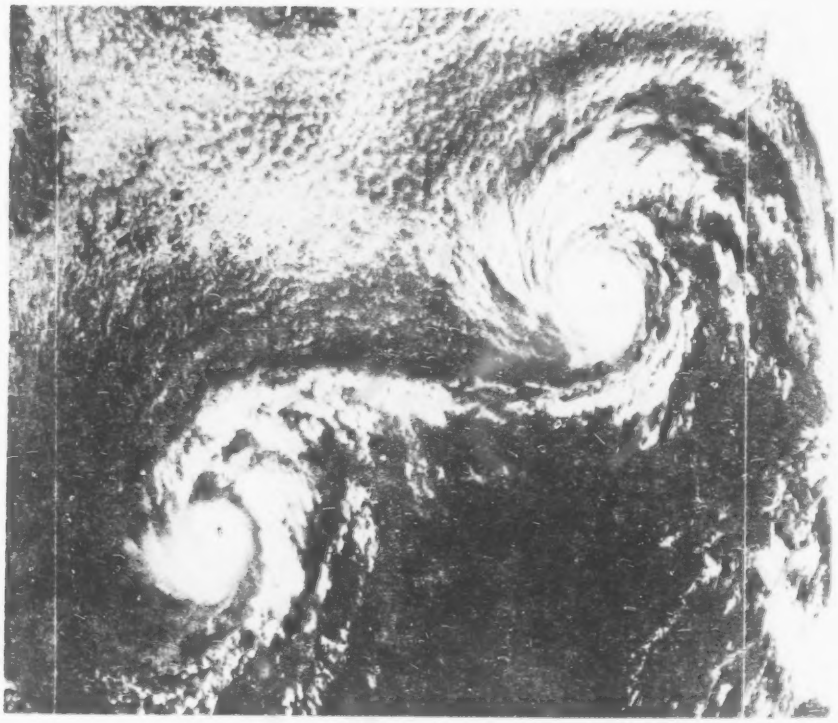


Photo credit: National Aeronautics and Space Administration

Twin hurricanes directly beneath a polar-orbiting NOAA spacecraft over the Pacific Ocean on Aug. 24, 1974

PROCESS INTERCHANGE IN THE EARTH'S ATMOSPHERE

Our life system on Earth is crucially dependent on a delicate balance and interchange of processes that occur at the interface of the Earth, the oceans, and the atmosphere. The presence of man and, in particular, the population explosion, compounded with the growth of industry, have begun to affect that balance in ways that are not yet understood. One primary means of monitoring and understanding these processes is through satellite remote sensing, an activity that is only a decade old.

Sampling the troposphere, the stratosphere, and much of the ionosphere can be done by Earth-based methods; the magnetosphere can be investigated only by space vehicles. The parameters of the "middle atmosphere," the region from 30 or 40 to 100 km above the Earth's surface, are still

uncertain, especially the composition and the electric fields of the region. If the effects that solar variations and the Van Allen Belt will have on spacecraft operating near the Earth are to be understood, the magnetosphere must be fully mapped throughout the solar cycle.

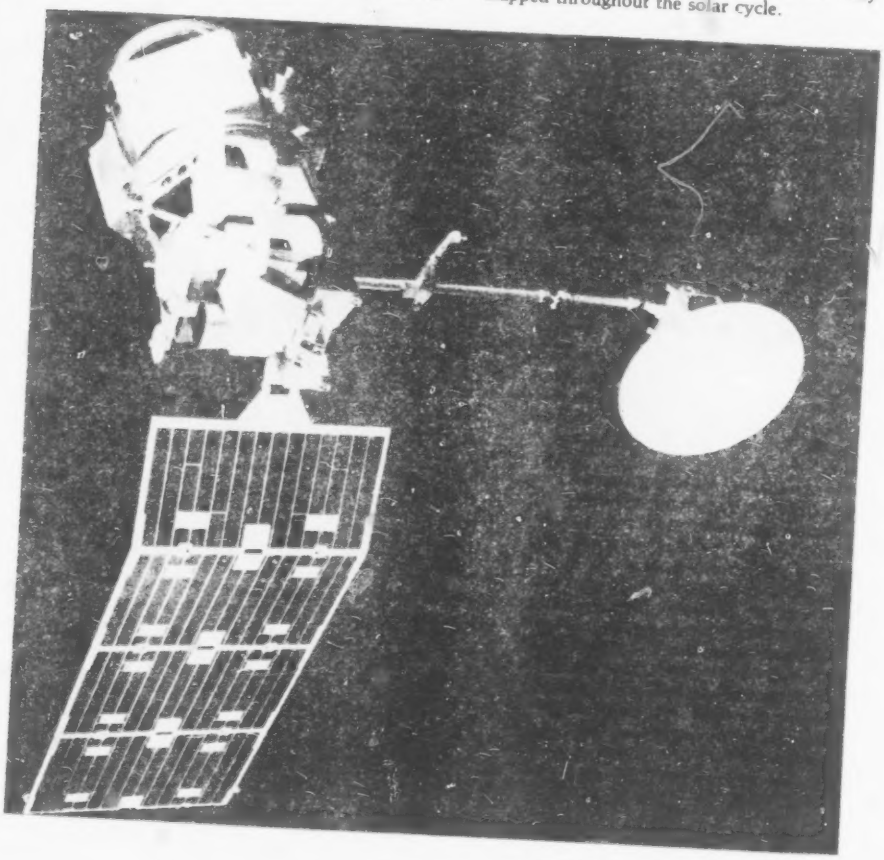


Photo credit: National Aeronautics and Space Administration

Landsat D—launched July 1982

EFFECTS OF SOLAR VARIATIONS ON COMMUNICATIONS

The Sun is the primary driving power underlying most processes on Earth, and its presence is an absolute necessity for our own existence. But the Sun is variable, and most of the variations that can occur have important effects on communications systems. Many of the important variations, however, can be seen only in regions of the spectrum accessible from above the Earth's atmosphere.

It had been known for decades that geomagnetic storms on the Earth seriously affect communications on the Earth, particularly at high latitudes. Geomagnetic storms result from streams of hot ionized gas that originate in solar storms, then are shot into interplanetary space, and finally impinge on the Earth's magnetosphere and disrupt communications. It is now known that the geomagnetic storms coincide with the arrival of streams of matter that travel much faster than the normal solar wind, and that these high-speed streams originate from regions on the Sun that do not emit X-rays, regions where there are "holes" in the low-energy X-ray emission, seen on photographs of the Sun taken in X-ray light. Thus, the presence of solar coronal holes, dark regions on an X-ray photograph of the solar disk, correlates significantly with geomagnetic storm activity on Earth.

Thus, there is a direct connection between the reliability of radio communications at high altitudes on Earth and our ability to monitor and study the Sun by X-ray satellites, by means of techniques not possible from the ground. The manifestations of this connection are not yet highly predictable, and the benefits of making them so will accrue only if basic research is continued.

SATELLITE RELIABILITY

Spacecraft operate in an environment that is largely foreign to us and virtually impossible to duplicate for study on the ground. In addition to the primary hazard of energetic particles in Earth's radiation belts, they are subject to differential charging, to emissions of electrons, protons, and other energetic particles from the Sun, to cosmic rays, and to high-energy solar and stellar ultraviolet, and X-ray and gamma ray radiation, any of which, if encountered in sufficient strength, can degrade the performance of the spacecraft. Damage may occur through irradiation of its detectors and electronics, electrostatic discharges, and the physical effects of collisions, including particle sputtering on mirror surfaces. As longer-lived satellites are orbited, degradation in performance because of environmental factors will be a more likely source of failure than will exhaustion of onboard energy sources.

The environment in which the now more than 4,000 manmade objects are orbiting the Earth is still not understood in detail. We do not yet know the time, frequency, or amplitude ranges over which variations in particulate bombardment and radiation take place. In the beginning of June 1980, for example, an unexpected increase in the flux of high-energy electrons at synchronous altitude particularly affected the performance of geostationary satellites. This result showed that the near-Earth space environment still held surprises and that instruments more immune to the effects of radiation had to be developed.

The requirement of the Department of Defense that the electronic components of its spacecraft be protected both against the natural radiation environment and, especially, against radiation from the explosion of nuclear devices has been the primary driver in the development of advanced "hardening" techniques. (The deep space probe Galileo, which must be able to withstand an environment of very high radiation around Jupiter, will be making use of some of these developments.) After these techniques are perfected, further study of the radiation environment around the Earth, particularly of the triggering mechanisms by which particles are dumped from the Earth's geomagnetic tail into the Earth's atmosphere, will be needed, if the national interest requires more assured satellite operations.

Common to civilian and military applications is the requirement to minimize payload weight while maximizing payload performance. This requirement has been the principal driving force behind the miniaturization of components, of which the development of tiny electronic circuits on silicon chips has been a major technological breakthrough. When these chips first found application on satellites, they were relatively large and not too densely packed. These features, combined with space hardening techniques, made the chips relatively reliable in the spacecraft environment. However, the technological state of the art in making chips has now progressed to the point where the chips are smaller and more densely packed, and have, size for size, orders of magnitude more capability than the previous generation of chips they will replace.

It is known that the new, high-density chips will be more susceptible to damage from radiation bombardment than were their predecessors, but it is not known how much more susceptible they will be. Here is another instance in which, if the answer is to be achieved, basic and applied research will both be needed: basic research to investigate the radiation environment, and applied research to investigate the effects of that environment on the new series of chips in order to predict how long they will last under various environmental conditions and under various degrees of radiation hardening.

COMMERCIAL IMPORTANCE OF NEAR-EARTH SPACE

The commercial importance of the space environment near the Earth has not yet been fully evaluated because, apart from the communications industry, there has been little involvement of the private sector. In the future, the investment of the private sector in space activities will almost certainly increase, particularly in satellite communications, remote sensing, and materials processing.

Materials processing in space (MPS) may be singled out as a new and interesting area for commercially oriented space research. In order to ease the way for industry to exploit the possibilities of MPS, NASA has developed the Joint Endeavor Agreement, in which the agency and industry share in the costs and the risks of the project: NASA provides technical advice and assumes the costs of the launch vehicle, including flight time, and industry provides the development funds.

One promising example of this Government-industry symbiosis is in drug manufacturing, where McDonnell Douglas Astronautics and the Ortho Pharmaceuticals Corp. of Johnson & Johnson are making a substantial investment in order to determine whether certain drugs can be manufactured in space more profitably than on the ground. Studies have shown that, by means of a process known as electrophoresis (a technique whereby a solution flows through an electric field in which molecules of different charges are separated from each other as a result of their migration in different directions at different speeds), it should be possible for cells to be separated from proteins about 100 to 400 times more quickly and with five times the product purity that can be obtained from the ground.

There are potential applications in the manufacture of interferon (a treatment for cancer), beta cells (a possible single-injection cure for diabetes), epidermal growth factor products (for treating burn patients), growth hormone products (for juvenile bone growth stimulation and the healing of ulcers), antitryspin products (for limiting the progress of emphysema), and antihemophilic products (for eliminating immunological reactions for hemophilia). In all these cases, there is promise that commercially viable quantities of these drugs can be made in the zero-gravity environment of space.

Materials processing is only one example of the possibilities of industrial use of near-Earth space. If these possibilities are to be exploited, scientists will require a better knowledge of the space parameters that may modify processes whose ground-based instances are well understood. If these developments are to be successful, continued interaction between pure space science and applied space science will be necessary.

Appendix A

Trends in the Space Science Budget

It is instructive to view the total NASA budget in the context of recommendations that were made within the administration in 1969, the year of the first Apollo landings on the Moon. Recognizing that the Nation needed to take a close look at the space program in the post-Apollo era, the President in February 1969 formed a Space Task Group (STG) to study the future course of the U.S. space program. STG was chaired by the Vice President, with membership from the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and the office of President's Science Advisor.

The report, entitled "The Post-Apollo Space Program: Directions for the Future," was received in September 1969. It presented a comprehensive plan which presented three possible program levels to achieve five program objectives: 1) increased emphasis on activities that have service to man (an expanded space applications program); 2) an enhanced defense posture for the Nation; 3) continuation of a strong program of space research to increase man's knowledge of the universe; 4) development of new systems and technology for space operations, emphasizing certain critical factors as: a) commonality, b) reusability, and c) economy, through the development of a new space transportation capability and space station modules; and 5) promotion of programs that provide broad international participation and cooperation.

The three program levels all contained a space shuttle, a 12-man space station, a 100-man space base, and lunar orbiting and surface stations. Two of the three options also included a manned mission to Mars. The time frames of these options differed, depending on the annual budgets projected for the future, which varied from $6 billion to $10 billion per year (1969 dollars). Figure A-1 shows a comparison of those NASA funding options (I, II and III, with a low-level bound having no manned flight). The upper curve marked "maximum pace bound" presents the funding required for a program limited not by funds, but by technology; the low-level program was constructed with an increased unmanned science and applications effort without a manned flight program. Figure A-1 also shows in 1969 dollars what level of funding for NASA actually was achieved.

In the post-Apollo era there was opposition to the levels of the space program proposed in the STG report which was expressed by critics in Congress, in the media, and in the American public generally and which led to a stretched-out time schedule shown in figure A-1. The actual program included the development of the space shuttle, but the rest of the recommendations of STG were not implemented. At the moment, no effort to develop a space station has been approved by the administration, despite the fact that the Soviet Union has been very active in developing a strong capability in this field for a number of years and will soon be able to sustain a permanent presence of man in orbit, either around the Earth or around the Moon.

Figures A-2 and A-3 show the space science budget of the NASA Office of Space Science and Applications (OSSA) from fiscal year 1964 to fiscal year 1983, expressed in millions of (1983) dollars, corrected for inflation.[1]

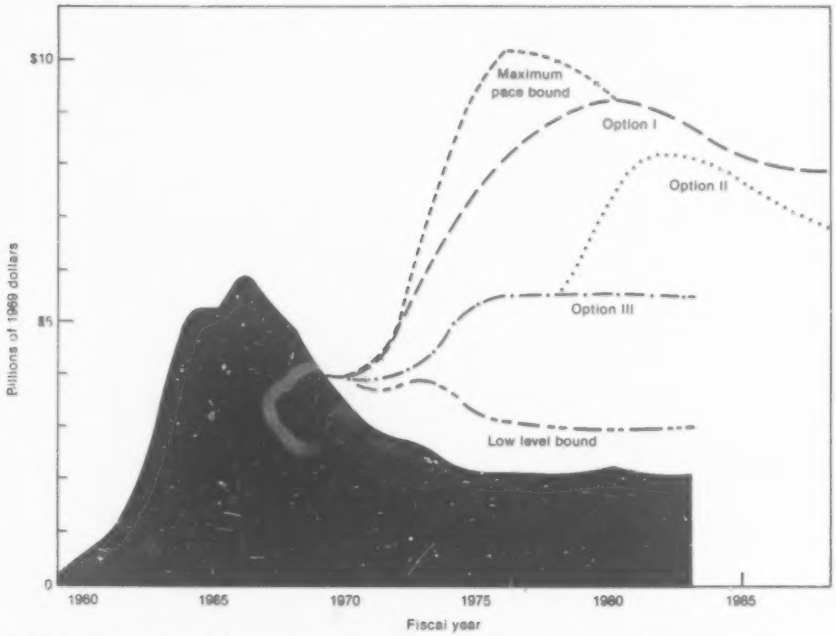
They are expressed in numerical form in tables A-1 and A-2. Three major components of the space science budget are shown: 1) the planetary sciences program, 2) the physics and astronomy program, and 3) the life sciences program. The factors by which actual budget figures have been converted to constant dollar figures are given in the middle (escalation) columns in table A-1. Table A-2 shows the budgets for individual flight programs during the same time interval, expressed in current-year dollars.

Several features of figures A-2 and A-3 deserve mention. First, in terms of purchasing power, the *total* budget for space science from the mid-1960's to the present time has fallen from about $1,450 million to about $650 million, or to approximately 45 percent of its former size. Most of this decline took place precipitously between 1966 and 1969. The budget increased again, but by only 50 percent of its decline, from 1972 to 1975, but fell again to its current value of about $650 million by 1977.

Reference to the other components of figure A-2 shows the trends of those components during the same time interval. The physics and astronomy program decreased by approximately 50 percent in the decade from 1964 to 1974, but has regained about two-thirds of its former value since 1974, principally because of increased funding for Space Telescope. The planetary science program was cut to one-third of its 1965 level by 1969, but grew to slightly more than its 1965 level by 1972-74, principally because of funding support for the Mars Viking program and the beginning of the

[1]The budget figures for the NASA Office of Space Science and Applications were supplied to OTA by I. Duke Stanford (NASA/OSSA).

Figure A-1.—Annual NASA Expenditure and Options

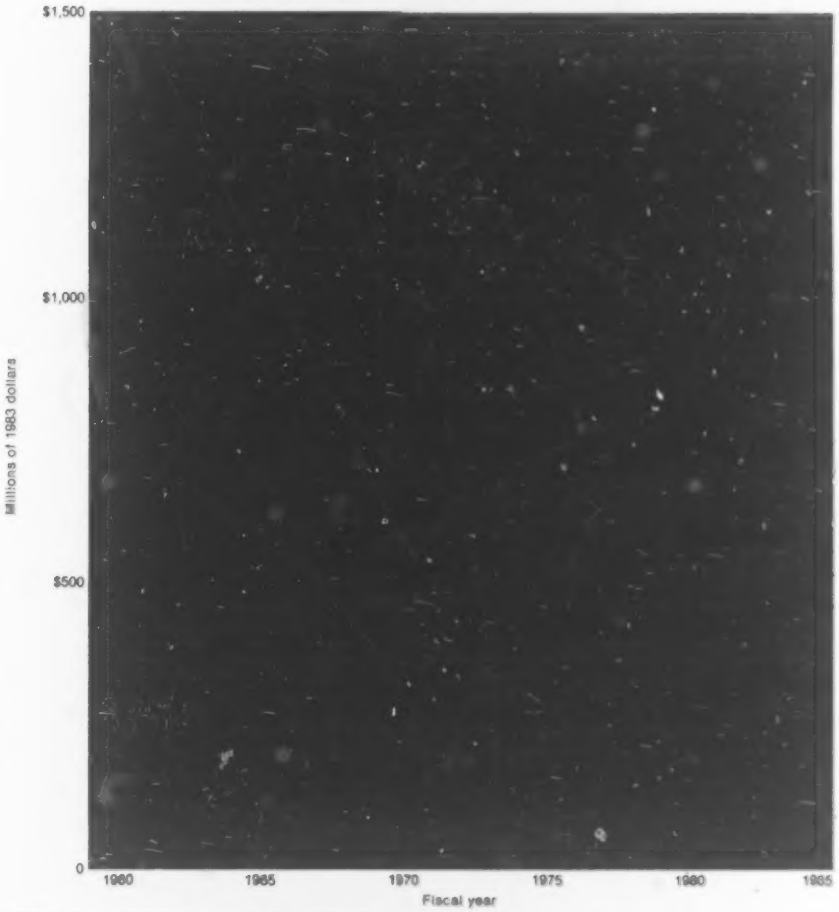


SOURCE: Space Task Group Report to the President, "The Post-Apollo Space Program: Directions for the Future," September 1969.

Voyager programs. However, as these programs tapered off, starting in 1974 and 1976, respectively, the budget for planetary sciences underwent a sharp decrease from its peak of $900 million (1983 dollars) to its current level of about $200 million, a drop to 22 percent of its value in 1974. The life sciences component of the NASA space science budget has remained relatively constant for the past decade.

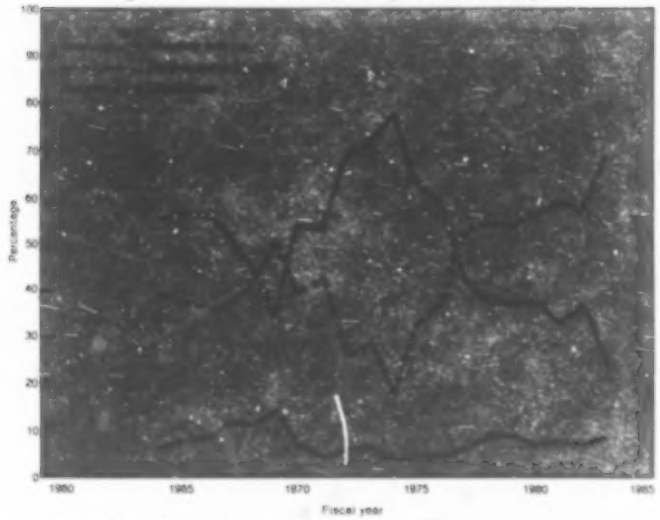
Reference to figure A-3 shows that the life sciences have typically taken about 510 percent of the space sciences budget for the past two decades. The budget for planetary science exceeded the budget for physics and astronomy from 1964 to 1968 and from 1970 to 1976, whereas the budget for physics and astronomy exceeded the budget for planetary science for 1969 and for the period from 1977 to the present. The budget for planetary science has been significantly lower in 1981-1983. It was noted that the fiscal year 1983 budget is still under discussion at the time of this writing (August 1982).

Figure A-2.—Budgets for NASA's Space Science Program



SOURCE: Office of Technology Assessment from NASA's supplied data.

Figure A-3.—Breakdown of NASA's Space Science Budget



SOURCE: National Aeronautics and Space Administration.

Table A-1.—Office of Space Science Funding Summary (dollars in millions)

Actual fiscal year	Actuals				Escalation[a]		In constant 1983 dollars			
	Physics and astronomy	Planetary	Life science	Total	Rate	Factor	Physics and astronomy	Planetary	Life science	Total
1964	148.6	205.8	21.5	375.9	3.7	3.983	591.8	819.7	85.6	1,497.1
1965	139.1	206.0	28.5	373.6	3.0	3.867	537.8	796.6	110.2	1,444.6
1966	142.8	221.4	34.4	398.6	4.1	3.714	530.3	822.2	127.7	1,480.2
1967	129.8	184.2	42.0	356.0	4.9	3.541	459.6	652.2	148.7	1,260.5
1968	139.5	147.5	41.8	328.8	5.4	3.359	468.5	495.4	140.4	1,104.3
1969	128.9	87.9	37.9	254.7	5.7	3.178	409.6	279.3	120.4	809.3
1970	112.8	150.9	19.7	283.4	6.9	2.973	335.3	448.6	58.5	842.4
1971	116.0	144.9	12.9	273.8	6.3	2.797	324.4	405.2	36.1	765.7
1972	110.1	285.5	22.8	418.4	5.7	2.645	291.3	755.4	60.3	1,107.0
1973	126.2	325.9	26.6	478.7	5.7	2.503	315.8	815.7	66.5	1,135.0
1974	94.0	387.7	22.8	504.5	7.2	2.335	219.4	905.2	53.2	1,177.8
1975	136.3	261.2	19.8	417.3	10.8	2.108	287.3	550.6	41.7	879.6
1976	159.3	254.2	20.5	434.1	9.0	1.934	308.0	491.6	39.8	839.4
1977	154.7	191.9	22.1	368.7	8.5	1.782	275.7	341.9	39.3	656.9
1978	212.6	147.2	33.3	393.1	7.8	1.653	351.4	243.3	55.0	649.7
1979	270.0	182.4	40.1	492.5	9.5	1.510	407.7	275.4	60.5	743.6
1980	336.8	219.9	43.8	600.5	10.7	1.364	459.3	299.9	59.7	818.9
1981	323.7	175.6	42.2	541.5	12.0	1.218	394.2	213.8	51.4	659.4
1982	323.5	205.0	39.5	568.0	10.7	1.100	355.8	225.5	43.4	624.7
1983[b]	(471.7)	(154.6)	(55.7)	(682.0)			(471.7)	(154.6)	(55.7)	(682.0)

[a]Based on NASA R&D Index dated September 1981.
[b]Proposed.

SOURCE: National Aeronautics and Space Administration.

Table A-2.—Space Science Budget From Congressional Submission

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Flight program	***$297.9***	***$283.0***	***$298.3***	***$249.5***	***$208.0***	***$146.0***	***$152.6***	***$184.5***	***$330.2***	***$366.7***	***$391.6***	***$277.7***	***$275.6***	***$168.0***	***$161.6***	***$278.6***	***$371.4***	***$282.0***	***$341.6***	***$425.3***
OSO's	20.0	18.8	19.1	10.1	11.3	13.9	14.9	16.9	18.6	20.4	12.8	4.3	3.6	1.0	1.3	—	—	—	—	—
OAO's	35.6	32.6	22.3	27.7	44.8	38.4	33.3	23.2	13.4	9.7	2.3	2.2	2.3	2.6	2.0	—	—	—	—	—
OGO's	42.9	30.3	28.2	24.8	20.1	13.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Explorers	15.5	21.8	18.6	18.2	17.5	19.1	18.3	28.9	22.8	33.2	32.8	34.0	29.9	30.2	24.3	31.3	32.3	33.3	33.3	34.3
HEAO	—	—	—	—	—	—	—	—	13.4	21.8	4.8	42.9	59.2	39.4	19.8	10.6	2.1	—	—	—
SL P/L	—	—	—	—	—	—	—	—	—	—	—	3.3	2.1	8.4	37.6	50.6	57.2	40.1	54.0	106.4
SMM	—	—	—	—	—	—	—	—	—	—	—	—	—	21.3	29.6	16.7	3.1	—	—	—
S-T	—	—	—	—	—	—	—	—	—	—	—	—	—	—	38.0	79.2	112.7	119.3	121.5	137.5
S. Polar	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12.5	47.9	28.0	5.0	21.0
GRO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6.2	8.0	34.5
Ranger	30.3	11.0	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Surveyor	70.0	81.8	104.6	79.9	33.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lunar Orbit	20.0	49.5	58.1	26.0	9.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mariners	49.2	17.4	17.6	43.2	66.2	46.2	53.9	41.8	61.6	37.7	11.1	5.3	—	—	—	—	—	—	—	—
Voyager '73	—	7.2	17.1	12.7	0.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pioneer	13.6	15.0	12.7	6.9	6.0	4.7	22.6	41.7	15.2	11.6	—	—	—	—	—	—	—	—	—	—
Viking	—	—	—	—	—	12.4	40.0	35.0	176.2	232.2	299.4	89.0	39.5	—	—	—	—	—	—	—
Pioneer-Venus	—	—	—	—	—	—	—	—	—	—	—	26.9	56.6	42.8	20.0	—	—	—	—	—
Voyager '77	—	—	—	—	—	—	—	—	9.2	6.1	27.4	59.2	82.4	50.3	—	—	—	—	—	—
Galileo	—	—	—	—	—	—	—	—	—	—	—	—	—	—	21.0	78.7	110.1	60.1	130.0	92.6
Res. Base	***78.1***	***80.8***	***88.3***	***108.5***	***120.0***	***106.7***	***90.0***	***88.3***	***86.2***	***110.0***	***122.9***	***136.6***	***168.5***	***172.7***	***201.6***	***212.9***	***238.1***	***248.6***	***238.3***	***112.1***
MO&DA	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	84.8	85.9	100.7	88.3	112.1
R&A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	128.1	133.2	148.9	137.9	144.6
Total OSS	***$375.9***	***$373.6***	***$386.6***	***$366.0***	***$328.0***	***$254.7***	***$283.4***	***$273.8***	***$416.4***	***$476.7***	***$504.5***	***$417.3***	***$434.1***	***$368.7***	***$393.1***	***$492.5***	***$609.5***	***$541.5***	***$595.0***	***$652.0***

Flight programs	*Number of missions*
OSO's	8
OAO's	4
OGO's	6
Pioneers	15
HEAO's	3
Rangers	9
Surveyors	7
Mariners	10

SOURCE: National Aeronautics and Space Administration.

Appendix B

Successive Galileo Cost Estimates

Table B-1.—Chart of Galileo Cost Estimates (in 1982 dollars)

Date of cost estimate	Cost estimate	Launch date
1977 (for 1978 start)	$455 million	January 1982
January 1980	$650 million[a]	February 1984 (orbiter) March 1984 (probe)
February 1981	$695 million[b]	April 1985
February 1982	$865 million[c]	May 1985
July 1982	$(pending)[d]	May 1985

[a]With three-stage IUS.
[b]With Centaur.
[c]With two-stage IUS with kick stage.
[d]With Centaur.

SOURCE: Figures provided by Klein Spencer, U.S. General Accounting Office.

Appendix C

Budget for Space Telescope

Table C-1.—The President's Fiscal Year 1983 Budget for Space Telescope (dollars in millions)

	Fiscal year							
	1978	1979	1980	1981	1982	1983	Budget to completion	Total
Space telescope development	$36.0	$79.2	$112.7	$119.3	$121.5	$137.5	$117-167	$725-775
Space telescope operations[a]	—	—	1.8	6.7	13.2	32.8	continues	

[a]Fiscal year 1982 and prior funding to the Space Telescope Science Institute is $5.6 million and fiscal year 1983 funding is $7.0 million. The estimated cost of the Space Telescope Science Institute facility, located at Johns Hopkins University, is $10 million.

SOURCE: Figures provided by Lynne Murphy, Congressional Liaison Office, National Aeronautics and Space Administration Headquarters.

Appendix D

Shuttle/ELV Price Comparison

The estimated price to place a 2,750 lb spacecraft into geosynchronous transfer orbit if launched in 1982 is as follows:

	Shuttle (in millions)	Delta (in millions)
Transportation	$ 8	$ 30
Upper stage	4-5	3-4
Total estimate*	$12-13	$33-34

The above shuttle price is derived using the shuttle introductory period price of $18 million (in fiscal year 1975 economics) for a dedicated shuttle launch during the 1982-85 timeframe. If the recently established $38 million price (in fiscal year 1975 economics) for a 1986-87 launch is used, the equivalent price for a 1982 launch would be:

	Shuttle (in millions)	Delta (in millions)
Transportation	$ 17	$ 30
Upper stage	4-5	3-4
Total estimate*	$21-22	$33-34

*Costs include payload integration.

SOURCE: Estimates courtesy of Robert V. Lottman, Director, Congressional Liaison Office, National Aeronautics and Space Administration Headquarters.

Appendix E

Economics of the Space Shuttle

by James A. Van Allen

In April 1982, James A. Van Allen of the University of Iowa presented to a meeting of Tau Beta Pi a paper entitled "Applications of Space Research to Modern Day Society." In preparation for the May 5 OTA workshop in which he participated, Van Allen sent a copy of that paper to OTA. Included here is the section of that paper in which he treats the economics of the space shuttle. Van Allen's analysis, which differs markedly from NASA's, is included in order to show how the space shuttle may have, more or less directly, affected the funding for space science. It is included with only minor explanatory comments. The reader should note that Van Allen includes overhead costs* in his calculations; these costs are not included when calculating marginal costs.[1]

The opinions expressed by Van Allen are his own and do not necessarily reflect those of OTA.

> There were many . . . weaknessess in the famous forecast of $100 per pound into orbit . . . I have prepared several (charts) analyzing the economics of the shuttle. The summary of this analysis is that there is no prospect whatever of bringing shuttle launch costs below some $5,000 per pound (1982 dollars). Even this figure is optimistic because my assumed payload of 60,000 lb per flight includes the mass of upper stages and other equipment that is not properly classified as useful payload.
>
> Hence, for realistic missions during the next 20 years or so, the shuttle system is actually much more expensive than are conventional, expendable boosters as exemplified by Delta, the Atlas-Centaur, the Titan-Centaur, and the French-German Ariane, all of which are in the advanced state of development and available for frequent use.

*Overhead costs are defined to be the fixed costs of the Federal establishment and associated contractors for maintaining the full operational capability of conducting a program of space shuttle flights, whether or not such flights actually occur.

[1]See, for example, Engel, Rolf, 1982, *Interavia* vol. 2, No. 177.

Table E-1A.—Shuttle Economics (Federal Government)

N = Number of flights per year
O = Annual overhead
A = Out-of-pocket costs per flight
P = Cost per payload
M = Mass of payload
C = Cost per flight
L = Launch cost per pound of payload

$$C = \frac{O + N(A + P)}{N}$$

$$L = \frac{O + NA}{NM}$$

OTA's comments: Table E-1A gives Van Allen's basic equation in which the quantity C, the cost per flight, is expressed as a function of overhead costs, the number of flights per year, the out-of-pocket costs per flight, and the cost per payload.

Table E-1B.—Shuttle Economics (Federal Government)

Examples:
O = $2,000,000,000 per year
A = $40,000,000 per flight
P = $100,000,000 per payload
M = 60,000 lb

N	Annual total	C	Launch cost per lb of payload
1	$2,140,000,000	$2,140,000,000	$34,000
3	2,420,000,000	806,700,000	11,780
10	3,400,000,000	340,000,000	4,000
50	9,000,000,000	180,000,000	1,300

OTA's comments: Table E-1B uses Van Allen's basic formulas of table E-1A to compute values of launch cost per pound of payload as a function of the number of flights per year N for assumed values of O, A, P, and M as listed at the head of table E-1B.

Van Allen's comments: This analysis ignores overhead during the 10-year developmental period: amortization of the investment for development of the vehicle and for facilities; and interest on the investment during the developmental and amortization periods.

Note that often quoted "marginal" or incremental launch cost per flight is the quantity A, a grossly unrealistic representation of the true cost. For the examples given here the "marginal" launch cost per pound of payload is $670, irrespective of the number of flights per year.

Note: "Payload" includes upper stages, if they are necessary, plus other equipment not properly considered useful payload.

Table E-2A.—Shuttle Economics
(Private enterprise/Federal Government)

Van Allen's comments:
Assumed: That the Space Transportation System including facilities had been developed by private enterprise and then had been taken over by the Federal Government.
I = direct investment costs accrued linearly as a loan over a period of 10 years
The direct investment costs plus interest over the developmental period are then amortized linearly over an operational period of Y years by the Federal Government.
X = annual interest rate over (10 + Y) years
In this case the *additional* annual cost averaged over the Y years of operational use is given by
$Z = (I + 51X) (1/Y + X/2)$
Numerical examples are given in table E-2B for N = 1, 3, 10, and 50 launches per year.

Table E-2B.—Shuttle Economics
(Private enterprise/Federal Government)

Examples:
I = $15,000,000,000
Y = 15 years
X = 0.1 (10%)
Z = $2,625,000,000

N	Annual total	C	Launch cost per lb of payload
1	$4,765,000,000	$4,765,000,000	$77,750
3	5,045,000,000	1,681,700,000	26,360
10	6,025,000,000	602,500,000	8,380
50	11,625,000,000	232,500,000	2,270

Van Allen's comments: "Payload" includes upper stages, if they are necessary, plus other equipment not properly considered useful payload.
Assumed values of O, A, P, and M are the same as in table E-1B.
All estimated cost figures in tables E-1A, 1B, 2A, and 2B are given in 1982 dollars.

OTA's comments: Table E-2B uses the formula of table E-2A to calculate four specific examples of the launch cost per pound of payload. Taking a developmental cost of $15 billion amortized over 15 years at an interest rate of 10 percent, Van Allen calculates that for 1, 3, 10, or 50 flights per year, the total (*not* marginal) launch cost per pound of payload will be $77,750, $26,360, $8,380, or $2,270, respectively.
Van Allen's calculations are intended to call into question the assertion that the shuttle will be able to bring the launch cost per pound of payload down to $100 to $300/lb. It should be noted, however, that this figure is the *marginal* launch cost per pound of payload, and that Van Allen's calculations are based on the *total* launch cost per pound of payload. It is, of course, the *total* cost of the shuttle which has had an impact on the space program.

Appendix F

Space Science Workshop Participants, May 5, 1982

Alastair G. W. Cameron
Harvard College Observatory

Thomas M. Donahue
Department of Atmospheric and Ocean Sciences
University of Michigan

Herbert Friedman
National Academy of Sciences

Riccardo Giacconi
Space Telescope Science Institute

Louis J. Lanzerotti
Bell Laboratories

Robert M. MacQueen
NCAR—High Altitude Observatory

Harold Masursky
Branch of Astrogeologic Studies
U.S. Geological Survey

David Morrison
University of Hawaii
Institute for Astronomy

Frederick L. Scarf
TRW

Erick O. Schonstedt
Schonstedt Instrument Co.

Bradford A. Smith
Department of Planetary Sciences
University of Arizona

Edward C. Stone, Jr.
Division of Physics, Mathematics and Astronomy
California Institute of Technology

John W. Townsend, Jr.
Fairchild Space & Electronics Co.

James A. Van Allen
Physics and Astronomy Department
University of Iowa

A. Thomas Young
Martin Marietta Aerospace

Appendix G

Additional Contributors

Scientific contributions were received from:

James R. Arnold
Lorenzo Bell
Michael J. S. Belton
William Bishop
Peter B. Boyce
P. Robin Brett
Geoffrey Briggs
Alastair G. W. Cameron
Herbert Carlson
William E. Carter
Clark R. Chapman
Robert Chapman
Lawrence Colin
Ted Cress
Arthur Davidson
John R. Dickel
Thomas M. Donahue
Michael B. Duke
William G. Fastie
Paul Feldman
Herbert Friedman
Riccardo Giacconi
Isaac Gillam
Bruce Gregory and Space Science Board
Herbert Gursky
Donald N. Hall
Richard C. Henry
Noel Hinners
Odette B. James and Lunar and Planetary Sample Team
Francis S. Johnson
Kenneth Johnston
Frank J. Kerr
Ronald Konkel
S. M. Krimigis
Louis J. Lanzerotti
Eugene H. Levy
Frank MacDonald
Robert M. MacQueen
Franklin Martin
Harold Masursky
H. Warren Moos
David Morrison
Tom Murdock
Randall Murphy
Eugene N. Parker
George Paulikis
Dennis Peacock
Charles Pike
Ron Posadro
Tom Poterma
Ronald Prinn
Robert Proodian
Henry Radowski
Lawrence Randall
Jefferey Rosendahl
Rita Sagalyn
Michael Sander
Frederick L. Scarf
Chris Schade
Erick O. Schonstedt
Francois Schweitzer
George Simon
Bradford A. Smith
Vernon Soumi
Andrew Stofan
Edward C. Stone, Jr.
Gerald F. Tape
Shelby Tilford
Alan Title
John W. Townsend, Jr.
Paul Try
James A. Van Allen
Martin Walt
Gerald J. Wasserburg
Laurel L. Wilkening
Andrew T. Young
A. Thomas Young

In addition, discussions regarding the study were held with:

L. P. Bautz
Darrell Branscome
Albert Bridgewater
Radford Byerly
Wesley Clark
John Dill
Steven Flajser
Sybil Francis
Edward Hall
Donald Heinrichs
C. Lincoln Hoewing
Diana Hoyt
Carol Lane
Richard Malow
Phyllis Minn
Steven Moore
Susan Podolsky
Jack Seum
Ira Shapiro
Marcia Smith
Scott Ulm
John Warner
Leonard Weiss

EXECUTIVE SUMMARY

QUANTIFYING THE BENEFITS TO THE NATIONAL ECONOMY FROM SECONDARY APPLICATIONS OF NASA TECHNOLOGY

Prepared for:

The National Aeronautics and Space Administration
Washington, D.C. 20546
In response to Contract No. NASW-2734

by:

Mathematica, Inc.
P.O. Box 2392
Princeton, N.J. 08540

June 30, 1975

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INTRODUCTION

In the 1958 law establishing the National Aeronautics and Space Administration, Congress charged NASA with conducting its research activities "so as to contribute ... to the expansion of human knowledge of phenomena in the atmosphere and space." Recognizing that such knowledge, like much of the knowledge generated by research, could also have potential applicability in non-aerospace sectors of the economy, Congress further directed NASA to "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

NASA's success in accomplishing its aerospace objectives is unquestioned. The achievements of the satellite programs, manned space flights, and exploration of the moon are dramatic and well-known. Less clear, however, is the extent to which the knowledge developed in the NASA programs has been useful outside its originally intended aeronautical and space applications. While literally hundreds of instances of non-aerospace applications, ranging from the cardiac pacemaker to gas turbines, have been cataloged, hardly anything is known of the quantitative economic significance of NASA's contributions.

The purpose of this study was to develop preliminary estimates of the economic benefits to the U.S. economy from secondary applications of "NASA technology." If technology is defined as the body of knowledge

concerning how society's resources can be combined to yield economic goods and services, then NASA technology represents NASA's contribution to this body of technical knowledge. Secondary applications refer to uses of NASA generated knowledge for purposes other than those primary mission-oriented ones for which the original R&D was done. These applications occur whenever a non-NASA entity, with or without encouragement from NASA, uses this knowledge in some economic activity.

B. MEASUREMENT APPROACH

The development of procedures to quantify the economic benefits of secondary applications involved the adoption of concepts and tools that are theoretically sound and yet practically useful in dealing with a wide variety of applications of NASA technology. There are two key foundational elements of the approach: one, an understanding of how technological change generates economic benefits; and two, a determination of the role that NASA can play in the process of technological change.

1. The Economic Benefits of Technological Change

In broad terms, the economic process involves the conversion of society's stock of resources into goods and services and the sale or exchange of these goods and services in the marketplace. This activity generates economic benefits by allowing people to consume desired combinations of goods and services. Advancing technology increases these benefits by allowing society to get more from the same stock of resources.

The specific methods for quantifying economic benefits have been the subject of much discussion in the economics literature. The most widely accepted principle for evaluating economic benefits is founded on individuals' "willingness to pay" to move from a "less" to a "more" preferred state. What this principle translates into for the purposes here is that the benefits of technological change can be measured as the cost savings generated by new or improved production processes plus the extra value that consumers attach to new or improved final products. Therefore, by determining how cost and demand for various products are affected by specific technological advances, one can estimate the benefits of these advances.

2. The Benefits Due to NASA

The research process by which technological advances are generated typically involves a complex interaction of various groups and individuals. In solving the particular problems associated with an advance, the individual research "actors" build on or combine their results with those generated by others. As a result, any "credit" for the benefits created by a particular advance should, in a real sense, be shared by the various contributors.

The goal here, of course, is to assign a particular share to NASA in some specific cases. The method for assigning this share is based on the premise that NASA R&D led to an earlier realization

of the particular technological advances being considered. In other words, had NASA not done its R&D -- and had its failure to do so not led to changes in R&D by others -- these technological advances would indeed have occurred, but at a later date.

If one accepts this view of technological advance -- and it has been proposed and defended by a number of authors -- then the measurement of benefits attributable to NASA becomes, at least theoretically, a rather straightforward task. These benefits can be measured as the difference between the present value of two benefits streams: one, the stream resulting from the advance as it has occurred, and two, the stream that would have resulted had NASA not been involved.

In each of the specific cases technical experts outside the NASA establishment were questioned about the speed-up resulting from NASA's role. Of course, there was some variation in their judgment. In order to allow for the inherent uncertainty in this aspect of the study, calculations were made based on alternative assumptions concerning the extent to which NASA accelerated the time stream of benefits. More specifically, benefits were calculated based on a minimum, a maximum, and a conservative "probable" speed-up due to NASA.

C. RESULTS OF CASE STUDIES

Before describing the results of the analysis, three points are worthy of mention. First, the case studies are by no means

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a random selection from the possible cases which might have been examined. Cases were deliberately selected where data were available, where NASA's role was widely acknowledged, and where benefits were anticipated to be relatively large. Consequently, until additional experience with more case studies is acquired, it is not possible to draw inferences regarding the total secondary benefits of NASA's R&D. Second, because the case selection was not random and because of the innovative nature of the work, an effort was made to be conservative in the calculations. Third, the brief discussion of the cases which follows is not sufficient for a full understanding of the qualifications and limitations of the analyses. To acquire a more complete comprehension of these, a careful reading of the technical report is required.

1. Cryogenic Multilayer Insulation Materials

NASA's role in cryogenic technology is an outgrowth of the effort to minimize the weight, volume, and evaporative loss of gases used in launch and flight propulsion systems, life support systems, and power generation on board spacecraft. An integral part of this general concern was the design of improved insulation systems. The development of cryogenic insulation technology has contributed substantially to the rapid growth of the cryogenics industry.

In this case study, benefits are calculated as the cost savings generated by the use of multilayer insulation instead of the next best

insulation material (perlite) in the transport of liquid hydrogen, liquid helium, and liquid nitrogen. It should be emphasized that other savings arise from the use of multilayer insulation with liquid hydrogen, helium, and nitrogen, insofar as it is used to insulate storage tanks, piping and other equipment used in the production of these liquid gases.

The two principal sources of measured cost savings due to multilayer insulation are: reduced boil-off loss during the time the cryogen is transported, and reduced transportation costs due to the lighter weight of multilayer insulated tanks. Benefits were estimated using an engineering approach to specify the relevant technical relationships between evaporation loss, weight, and insulation characteristics. The "best guess" or "probable" estimate of benefits is $1,054 million.

2. Integrated Circuits

Prior to 1960, conventional electronic circuitry was based on the assembly of individually-encapsulated circuit components such as transistors, resistors, capacitors, and diodes. Integrated circuit technology -- the combination of these circuit functions on an inseparable, continuous base--provides significant advantages over conventional circuit technology, particularly in smaller size, lower power consumption, increased speed of operation, improved reliability, and reduced cost per electronic function. These features make integrated circuits especially attractive for space applications.

The introduction of integrated circuit technology produced significant changes in all electronic products, including consumer electronic products, and the estimates of the total benefits to advancing integrated circuit technology reflect its very widespread applicability.

Based on a simultaneous equation estimation of the demand for integrated circuits, estimates of benefits were derived. The "probable" estimate is $5,080 million.

3. Gas Turbines in Electric Power Generation

Since the early 1940's NASA (then NACA) has been intimately involved in gas turbine technology, primarily as it relates to improvement of jet engines for military and commercial aircraft. This basic research has also produced benefits in the production of electric power, as gas turbines have become more widely used as sources of peaking power and standby capacity.

The use of gas turbines in electric power generation undoubtedly confers may social benefits; e.g., gas turbines are relatively "clean" from an environmental point of view and also enhance the reliability of power production. Nevertheless, the estimates of benefits are based only on the fuel cost savings in power production produced by improvements in gas turbine performance. Improvements in gas turbine performance are assumed to result from advances in turbine technology; gas turbine vintage was used as a proxy for technology level in these calculations. Using standard regression analysis, the relationship between gas turbine vintage and the average cost of fuel consumed in the production of power was estimated; based on this relationship, a "probable" estimate of the total fuel cost savings of $111 million was determined.

4. NASTRAN

NASTRAN (NASA Structural Analysis) is a general purpose finite element computer software package for static and dynamic analysis of the behavior of elastic structures. Industrial users are generally product engineers in mechanical or civil engineering applications such as aircraft and automobile production, bridge construction, or power plant modeling.

NASA's Goddard Space Flight Center developed NASTRAN, through a combination of in-house and contracted research, over the period 1965 to 1970. It represented substantial improvement over similar extant programs, and was released to public users in November of 1970.

Because few published data exist regarding the extent of use of NASTRAN, estimates of cost savings from the use of NASTRAN were obtained from telephone interviews with a sample of users. From the sample responses the "probable" benefits accruing to the population of NASTRAN users were estimated at $701 million.

D. SUMMARY AND CONCLUSIONS

A summary of the "probable" estimates for each case study is presented in Table 1. It indicates that total benefits due to NASA for the four cases studied are probably on the order of $7,000 million.

Table 1

Results of Benefits Estimation

Technology	Interval of Benefits Estimation	Estimated Probable NASA Acceleration (Years)	Probable Benefits Attributable to NASA (Millions)
Gas Turbines	1969 - 1982	1.0	$ 111
Cryogenics	1960 - 1983	5.0	$1,054
Integrated Circuits	1963 - 1982	2.0	$5,080
NASTRAN	1971 - 1984	4.0	$ 701
Total	—	—	$6,946

In interpreting the results of this study one should recognize that it is one of the first of its kind ever attempted. The results, while arrived at through careful and rigorous techniques, are sensitive to data uncertainties and analytical simplifications. Though one must necessarily view such results with caution, it seems that the following general observations could be safely made:

- Operational methods can be developed for estimating the secondary benefits of mission oriented R&D.
- Secondary benefits attributable to NASA's R & D programs may be impressively large. For example, the $7,000 million total for the four cases studied is more than twice NASA's present yearly budget.
- Because secondary benefits may indeed be significant, public decisions concerning the allocation of resources to research and development programs should, where possible, consider such benefits.

FINAL REPORT

THE ECONOMIC IMPACT OF NASA R & D SPENDING
EXECUTIVE SUMMARY

Prepared for:

National Aeronautics and Space Administration
Under Contract No. NASW-2741
Washington, D.C.

Prepared by:
Michael K. Evans
Chase Econometrics Associates, Inc.
Bala Cynwyd, Pa.
April, 1976

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Chase Econometrics

Abstract

In this study Chase Econometrics, Inc., has undertaken an evaluation of the economic impact of NASA R & D programs. The crux of the methodology and hence the results revolve around the interrelationships existing between the demand and supply effects of increased R & D spending, in particular, NASA R & D spending. The demand effects are primarily short-run in nature and have consequences similar to that of other types of government spending. The supply effects, which represent the results of a higher rate of technological growth manifested through a larger total productive capacity, are long-run in nature and have consequences very dissimilar to that of general types of government spending.

The study is divided into two principal parts. In the first part, the INFORUM Inter-Industry Forecasting Model is used to measure the short-run economic impact of alternative levels of NASA expenditures for 1975. The principal results of this part of the study are that a shift toward higher NASA spending within the framework of a constant level of total Federal expenditures would increase output and employment and would probably reduce the inflationary pressures existing in the economy. Hence, Chase concludes that NASA spending is more stabilizing in a recovery period than general government spending.

In the second part of the study, an aggregate production function approach is used to develop the data series necessary to measure the impact of NASA R & D spending, and other determinants of technological progress, on the rate of growth in productivity of the U. S. economy. The principal finding of this part of the study is that the historical rate of return from NASA R & D spending is 43 percent.

Chase Econometrics

In the final part of the study, the measured relationship between NASA R & D spending and technological progress is simulated in the Chase Macro-econometric Model to measure the immediate, intermediate, and long-run economic impact of increased NASA R & D spending over a sustained period. The principal findings of this part of the study are that a sustained increase in NASA spending of $1 billion (1958 dollars) for the 1975-1984 period would have the following effects:

1) Constant-dollar GNP would be $23 billion higher by 1984, a 2% increase over the "baseline," or no-additional-expenditure projections.

2) The rate of increase in the Consumer Price Index would be reduced to the extent that by 1984 it would be a full 2% lower than indicated in the baseline projection.

3) The unemployment rate would be reduced by 0.4% by 1984, and the size of the labor force would be increased through greater job opportunities so that the total number of jobs would increase by an additional 0.8 million.

4) By 1984 productivity in the private non-farm sector would be 2.0% higher than indicated in the baseline projection.

Other simulations, of $100 to $500 million increases, show proportional results.

The large beneficial economic effects of NASA R & D programs, particularly the unique combination of increased real GNP and a lower inflation rate, stem from the growth in general productivity resulting from NASA programs. Growth in productivity means that less labor (and/or capital) is needed per unit of output. This results in lower unit labor costs and hence lower prices. A

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slower rate of inflation leads in turn to a more rapid rise in real disposable income, which provides consumers with the additional purchasing power to buy the additional goods and services made possible by the expansion of the economy's production possibility frontier. Finally, the increase in real consumer expenditure leads to an increase in demand for the services of labor.

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Introduction

Chase Econometric Associates, Inc. has undertaken an evaluation of the economic impact of NASA R & D spending on the U. S. economy. This study reports on both the short-run and long-run effects of changing levels of spending. Both the Chase Econometrics macro model and input-output model are used to calculate the impact of different spending levels on the overall economy and on specific industries in the short-run part of the study. The long-run part of the study includes an estimate of the relationship between NASA R & D spending and the rate of technological growth. This relationship is used to determine how much higher spending levels would raise aggregate supply and increase the total productive capacity of the economy. The demand effects stemming from an increase in spending are not substantially different from traditional multiplier analysis and are primarily short-run in nature. The supply effects do not begin to have a significant effect on aggregate economic activity until five years later, but the ultimate effects are much larger and very different than the effects of most forms of government spending.

Short-Run Impacts of NASA R & D Spending

Description of Approach

The first part of the study deals with the short-term economic impact of NASA expenditures and attempts to answer the question of whether a higher level of NASA expenditures is more beneficial to the U. S. economy than a lower level during the year that the expenditures are made, holding the level of total

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Federal spending constant. This analysis is useful in examining the effects of altering the level of NASA expenditures as part of an overall economic stabilization policy.

The economic impact was calculated by preparing two forecasts of the U. S. economy for 1975 using alternative levels of NASA expenditures, which we term NASAHI and NASALO. The NASALO forecast assumed an expenditure by NASA of $1.35 billion in 1971 dollars for goods and services (excluding NASA employee wages) during calendar 1975. The NASAHI forecast assumed an expenditure of $2.35 billion by NASA with other Federal government spending reduced by $1 billion, hence leaving the total level of government spending unchanged. Because of this, the aggregate economic impact shown for this shift is quite small.

In order to measure the differential industry effect of the NASAHI and NASALO expenditure levels, we utilized the INFORUM Inter-Industry Forecasting Model. This model, which was developed by the Interindustry Forecasting Project of the University of Maryland, has been expanded and modified by Chase Econometrics and has been linked to the Chase Econometrics Macroeconomic Forecasting Model to provide consistent economic forecasts for the industries included in the model. Through use of this model, it is possible to forecast the impacts on major economic indicators such as inflation, employment, GNP, and productivity of a shift in the Federal budget to a higher level of NASA spending.

Short-Run Results

The effects of the two alternative forecasts on the aggregate economy, as estimated through use of INFORUM, are shown in Tables 1 and 2. While the results are not dramatic, they do indicate that the direction of change in economic activity from an increase in the level of NASA expenditure is positive

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TABLE 1

MACROECONOMIC IMPACT OF NASAHI AND NASALO EXPENDITURES

	NASALO 1975	NASAHI 1975
Gross National Product	1529.9	1530.1
Gross National Product (1958$)	820.7	820.7
Consumer Price Index (% change)	10.5	10.5
Disposable Personal Income	1084.9	1085.0
Federal Government Deficit	17.0	16.9

All figures are in billions of dollars except where indicated otherwise.
NASAHI = NASA expenditures during 1975 of $2.35 billion in 1971 dollars.
NASALO = NASA expenditures during 1975 of $1.35 billion in 1971 dollars.

TABLE 2

EMPLOYMENT BY INDUSTRIES AFFECTED BY A NASA SPENDING SHIFT

EMPLOYMENT BY SELECTED INDUSTRIES			HI (thousands)	LO (thousands)	DIFF
Industry Number	Industry	SIC Code			
5	Missiles and Ordnance	19	154	142	+12
59	Machine Shop Products	359	191	190	+ 1
67	Communication Equip.	366	404	402	+ 2
71	Aircraft		501	488	+13
	Total				+28
22	Logging and Lumber	241, 242	307	308	- 1
25	Furniture	25	543	544	- 1
27	Paper and Products	26	501	502	- 1
30	Printing & Publishing	27	688	689	- 1
31	Industrial Chemicals		295	296	- 1
72	Shipbuilding	373	169	171	- 2
	Total				- 7
	Net gain in Manufacturing Employment (thousands of jobs)				+20

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and beneficial. The magnitudes are small because the total Federal expenditure has not been altered and these improvements result solely from a shift within total Federal expenditures. Nonetheless, these results do indicate that NASA expenditures are less inflationary than other Federal government expenditures, and that a shift toward higher NASA spending with a constant Federal expenditure is not inflationary in the present economy. Conversely, it would follow that a shift away from NASA to other Federal programs could be relatively inflationary in the present economy. Further, the employment effect of NASA expenditures is beneficial, although not large for this small change, and thus both goals of higher employment and lower rates of inflation would be hindered by a lower level of NASA expenditure.

Thus in this section of the study we show that a shift to NASA expenditures from other Federal government spending will stimulate the economy without raising prices. In particular, we found the following effects of a shift of $1 billion in 1971 dollars.

1) A higher level of NASA expenditures would not have had an inflationary impact on the U. S. economy during 1975 and would probably have reduced the inflation pressures in the economy.

2) A shift of $1.0 billion in 1971 dollars, or $1.4 billion in 1975 estimated prices, from other Federal non-defense expenditures to NASA expenditures would have reduced the inflationary pressures in several key basic materials industries.

3) A shift to increase NASA expenditures would have increased employment by 25,000 in the missile and ordnance and aircraft industries. While it would have reduced employment in ten other industries, the net increase in the manufacturing sector would have been 20,000 jobs.

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4) Output would have been stimulated in twenty-one industries. The principal industries which would have been affected had considerable excess capacity in 1975 and were producing at levels well below their peak years and in most cases below the average of the past five years.

The general conclusion reached in this section is that a shift toward higher NASA spending within the framework of a constant level of total Federal expenditures creates jobs without raising the rate of inflation, and hence is more stabilizing in a recovery period than general government spending.

The Impact of NASA R & D on the Rate of Change of Technological Progress

Description of Approach

The second part of this study is an examination of the historical relationship between NASA R & D spending and the rate of technological progress. This examination requires two steps: (1) the construction of a time series to measure the rate of change of technological progress; and (2) an empirical investigation through regression analysis of the determinants of technological progress suggested by economic theory.

(1) Time Series for γ (gamma). The time series representing the rate of change in technological progress (γ) is a somewhat elusive measure, inasmuch as it requires developing a series for potential Gross National Product (GNP) as well as related series for labor and capital inputs. The series that was developed to measure γ is based on the methodology used by the Council of

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Economic Advisers. In addition, an alternative series for γ was developed, following the methodology of E. F. Denison, to test the sensitivity of the results to a change in the formulation of the γ series.

Our formulation of γ is as follows:

$$\gamma = \frac{\Delta X}{X} - \alpha \frac{\Delta L}{L} - (1 - \alpha) \frac{\Delta K}{K}$$

where X = full capacity or maximum potential output (national income or GNP) in constant prices

L = maximum available labor force

K = capital stock, defined as $K = \sum_{i=0}^{N} \lambda^i I_{t-1}$ where λ is the rate of economic depreciation and I is fixed nonresidential investment.

α = share of potential output

γ = the rate of technological progress (that is, the rate of increase in full capacity real GNP that cannot be accounted for by a change in either the size and composition of the labor force or the size and composition of the capital stock).

(2) Determinants of γ. Economic theory and prior econometric studies suggest the following possible determinants for γ: (a) R & D spending; (b) an industry mix variable; (c) an index of capacity utilization; (d) an index of labor quality reflecting changes in age mix, sex mix, health levels, and educational levels of the labor force; and (e) an index of economies of scale. After considerable experimentation, we found the latter two determinants to be insignificant for the time period examined. The exclusion of economies of scale as an explanatory variable for γ can be justified on theoretical grounds since this variable is generally relevant to only firm

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or industry or underdeveloped nation studies. The statistical insignificance of the labor quality variable may be partly explained by the fact that some of its characteristics are already reflected by the manner in which we constructed the labor force variable used to generate γ. Undoubtedly, the insignificance of the labor quality variable is also partly due to our inability to reflect significant improvements (variability) in labor education and training over an observation period as short as 15 years.

Hence, based upon both theoretical considerations and empirical investigation, we offer the following conclusions regarding the determinants of γ. First, R & D spending should be included as a determinant and should be subdivided into two explanatory variables, namely, NASA R & D spending and other R & D spending. Secondly, we found that both R & D variables could be closely approximated by a distributed lag structure that follows the general shape of an inverted U-distribution; that is, as a result of an increase in R & D spending in year 0, modest increases in the productivity growth rate begin in year 2, peak in year 5, and terminate in year 8. The actual distributed lag weights, determined by the Almon method and used in the study, are given in Table 3. Thirdly, an industry mix variable should also be used in the equation that attempts to explain movements in γ. This specification is necessary to capture the impact on γ of shifts over time in resource allocation from high- to low-technology industries. Finally, the equation expalining γ should also include a capacity utilization variable to account for the fact that shortages and bottlenecks reduce productivity growth as the economy approaches full capacity.

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TABLE 3

DISTRIBUTED LAG WEIGHTS FOR R & D SPENDING

Time Lag (Yrs.)	Proportional Weight
0	0.0
1	0.0
2	0.061
3	0.164
4	0.220
5	0.232
6	0.200
7	0.123
8 and later	0.0

The Measured Effect of R & D Spending on Productivity Growth

(1) The Regression Equation. The final regression equation which was used to explain γ in this study is as follows:

$$\gamma = -1.81 + \underset{(3.9)}{0.426} \sum_{i=0}^{7} A_i \, (NRD)_{-i} + \underset{(2.0)}{0.074} \sum_{i=0}^{7} A_i \, (ORD)_{-i} \, \frac{(1-Cp)}{(1-\overline{Cp})}$$

$$+ \underset{(4.5)}{0.031} \, (IM - \overline{IM}) - \underset{(3.1)}{0.157} \, (Cp - \overline{Cp})$$

$\bar{R}^2 = 0.883$
DW = 1.95
Sample Period 1960-1974

where: NRD = NASA R & D spending as a proportion of GNP

ORD = other R & D spending as a proportion of GNP

IM = industry mix variable, fraction

Cp = index of capacity utilization, percent

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The numbers in parentheses below the regression coefficients represent t-statistics. As can be seen from the regression results, all coefficients are statistically significant and the overall fit of the equation to the data, as measured by the $\bar{R}^2$ value of 88.3 percent, is impressively high, especially for a first difference equation.

(2) The NASA Contribution to γ. Using the regression results above, we found that the increased levels of constant-dollar GNP stemming from a $1 billion increase in constant-dollar NASA R & D spending in 1975 are as given in Table 4. For purposes of this calculation we hold the baseline level of GNP constant and ignore all interactive and dynamic demand and supply multipliers. As will be explained later, the actual changes in GNP will be considerably larger once we do include the effect of these multipliers.

TABLE 4

INCREASE IN GNP PER UNIT INCREASE IN NASA R & D SPENDING
"PURE" PRODUCTIVITY EFFECTS ONLY

Year	Cumulative Change in GNP
1975	0
1976	0
1977	0
1978	0
1979	0.26
1980	0.96
1981	1.90
1982	2.88
1983	3.74
1984 and succeeding years	4.26

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The rate of return on NASA spending may be found by substituting the results of Table 4 into the conventional rate of return formula. For a $1 increase in spending, the appropriate expression would be

$$\frac{0.255}{(1+r)^5} + \frac{0.952}{(1+r)^6} + \frac{1.888}{(1+r)^7} + \frac{2.882}{(1+r)^8} + \frac{3.736}{(1+r)^9} + 4.261 \left[\frac{\left(\frac{1}{1+r}\right)^{10}}{1 - \frac{1}{1+r}} \right] = 1.00$$

where r is the rate of return. Solving this equation yields r = 43% to the nearest percent. If we re-solve the equation by substituting $\frac{4.26}{(1+r)^{10}}$ for the last term, thus not assuming an infinite life, we find the rate of return diminishes to 38%.

Thus an increase of $1 billion in NASA R & D spending would increase productivity and total capacity of the U. S. economy by $4.26 billion in 1984 and each succeeding year. It should be stressed that this figure stems from a $1 billion increase in 1975 and then a return to previous spending levels. If spending were to remain $1 billion higher indefinitely, the first-order supply effects, i.e., disregarding interactive and dynamic effects, are shown in Table 5. As indicated above, the actual results are significantly larger because of the demand and multiplier effects calculated by simulating the Chase macroeconomic model.

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TABLE 5

CUMULATIVE EFFECT ON GNP OF A SUSTAINED
INCREASE IN NASA R & D SPENDING
"PURE" PRODUCTIVITY EFFECTS ONLY

1975													
1976													
1977													
1978													
1979	0.26											=	0.26
1980	0.96	+	0.26									=	1.22
1981	1.90	+	0.96	+	0.26							=	3.12
1982	2.88	+	1.90	+	0.96	+	0.26					=	6.00
1983	3.74	+	2.88	+	1.90	+	0.96	+	0.26			=	9.74
1984	4.26	+	3.74	+	2.88	+	1.90	+	0.96	+	0.26	=	14.00

Macroeconomic Impacts of NASA R & D-Induced Technological Progress

The third part of the study uses the relationship which has been developed between NASA R & D spending and the rate of technological progress to translate an increase in spending into a higher overall level of productivity for the U. S. economy. This section features a number of simulations with the Chase Econometrics macro model which determine the total effect of higher NASA R & D spending on the economy when interactive and dynamic effects are taken into account. These simulations consider the supply side of the economy as well as the demand side, and stress the fact that real GNP can be expanded by increasing productivity and lowering prices as well as by increasing government spending.

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Approach to Determining Macroeconomic Effects

Up to this point we have considered only the static supply or "pure" productivity effects of NASA R & D spending. We now employ the Chase Econometrics macro model to determine the effects of an increase of $1 billion in constant prices (1958 dollars) in NASA R & D spending. We assume that such spending is increased by this amount at the beginning of 1975 and remains in force throughout the next decade. There are two types of effects from this increased spending.

The first type of effect is the ordinary expenditure (demand) impact of increased government spending. The second type of effect--this effect being what really differentiates NASA R & D from other types of government spending--is the longer run impact of NASA R & D-induced changes in the rate of technological progress. These changes lead to an expansion in the productive capacity of the economy and ultimately lead to an increase in society's standard of living.

(1) The Expenditure (Demand) Impact of NASA R & D. In a period of economic slackness, an increase in government spending leads to increased real GNP and lower unemployment. These expenditure effects for NASA R & D are not markedly different than those experienced for most increases in other types of government spending or for the release of funds to the private sector for construction. It should be noted, however, that NASA R & D expenditure increases have a larger impact per dollar than similar spending on welfare or low productivity type job programs.

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(2) The Important Productivity Impacts of NASA R & D. The productivity impacts of NASA R & D generate social benefits in a somewhat more complex manner. We have already shown above (Table 5) the magnitude of increase which will occur in the productive capacity of the economy for an increase in NASA R & D spending. However, there is no automatic increase in demand which will occur just because total supply is now higher, and until this newly created capacity is utilized through higher demand no social benefits are realized.

There is an economic mechanism through which increased supply does create its own demand. Greater R & D spending leads to an increase in productivity, primarily in the manufacturing sector. As a result of this increase, less labor is needed per unit of output. This in turn lowers unit labor costs, which leads to lower prices. Yet this decrease is not immediately transferred into higher output and employment. As prices are lowered (or grow at a less rapid rate), real disposable income of consumers increases at a faster rate. Consumers can then purchase a larger market basket of goods and services, which in turn are now available because the production possibility frontier has moved outward. Yet these decisions are not instantaneous and friction-less, as they would be in an oversimplified static model. We do not see significant effects of increased technology on aggregate demand until 1980.

Results of Macroeconomic Simulations

Once the increase in productive capacity has worked itself into aggregate demand through the mechanisms discussed above, real growth is then fairly steady as can be seen from Table 6. In particular, we find that real GNP rises near $5 billion per year faster than would be the case under the

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TABLE 6

CHANGE IN SELECTED VARIABLES WITH AN INCREASE
IN NASA R & D SPENDING OF $1 BILLION

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Gross National Product, Billions of 1958 Dollars										
Base	788.1	834.0	869.6	859.8	868.5	922.4	977.7	1012.2	1059.6	1090.8
NASA	790.2	836.5	871.7	862.1	871.7	928.6	988.0	1035.0	1077.4	1114.1
Change	2.1	2.5	2.1	2.3	3.2	6.2	10.3	13.8	17.8	23.3
% Change	.3	.3	.2	.3	.4	.7	1.1	1.4	1.7	2.1
Consumer Price Index, 1967 = 100.0										
Base	161.1	173.9	188.4	204.9	219.4	232.0	244.2	257.0	270.9	286.5
NASA	161.0	173.8	188.4	204.7	219.0	231.0	242.2	254.0	266.9	280.7
Change	-0.1	-0.1	0.0	-0.2	-0.4	-1.0	-2.0	-3.0	-4.0	-5.8
% Change	0.0	0.0	0.0	-0.1	-0.2	-0.5	-0.8	-1.1	-1.5	-2.0
Rate of Inflation, %										
Base	9.1	7.9	8.3	8.7	7.1	5.8	5.2	5.2	5.4	5.8
NASA	9.1	7.9	8.3	8.6	7.0	5.5	4.9	4.9	5.0	5.3
Change	.0	.0	.0	-.1	-.1	-.3	-.3	-.3	-.4	-.5
Unemployment Rate, %										
Base	9.0	8.2	7.4	8.6	9.9	9.2	8.0	7.1	6.5	6.0
NASA	8.9	8.0	7.3	8.5	9.8	9.1	7.7	6.8	6.1	5.6
Change	-.1	-.2	-.1	-.1	-.1	-.1	-.3	-.3	-.4	-.4
Employees on Payrolls, Millions										
Base	76.9	79.9	82.8	83.3	83.2	85.3	88.1	90.5	92.5	94.3
NASA	77.0	80.0	82.9	83.4	83.3	85.5	88.4	90.9	93.1	95.1
Change	.1	.1	.1	.1	.1	.2	.3	.4	.6	.8
% Change	.1	.1	.1	.1	.1	.2	.3	.4	.6	.8
Index of Industrial Production, Manufacturing Sector, 1967 = 100.0										
Base	109.1	120.2	129.6	125.3	122.4	132.6	145.3	154.6	162.2	168.6
NASA	109.9	121.2	130.5	126.3	123.5	134.3	148.1	158.1	166.5	174.0
Change	.8	1.0	.9	1.0	1.1	1.7	2.8	3.5	4.3	5.4
% Change	.7	.8	.7	.8	.9	1.3	1.9	2.3	2.7	3.2
Index of Labor Productivity, 1967 = 100.0										
Base	110.2	112.1	113.3	112.5	115.2	120.1	123.9	126.9	129.9	132.0
NASA	110.3	112.2	113.4	112.7	115.5	120.8	125.1	128.6	132.0	134.7
Change	0.1	0.1	0.1	0.2	0.3	0.7	1.2	1.7	2.1	2.7
% Change	0.1	0.1	0.1	0.2	0.3	0.6	1.0	1.3	1.6	2.0
Change in Labor Productivity, %										
Base	-.4	1.7	1.1	-0.7	2.4	4.3	3.2	2.4	2.4	1.6
NASA	-.3	1.7	1.1	-0.6	2.7	4.6	3.6	2.7	2.7	2.0
Change	.1	.0	.0	0.1	.1	.3	.4	.3	.3	.4

Base = baseline projection with current estimates of NASA R & D spending for next decade.

NASA = an increase of $1 billion in 1958 dollars in NASA R & D spending.

Change = NASA - Base

% Change = $\frac{\text{NASA - Base}}{\text{Base}}$ Since the unemployment rate is already given in percentage terms, we do not calculate this item for unemployment.

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baseline simulation which does not include increased NASA R & D spending. Thus constant-dollar GNP is $6 billion higher in 1980, $10 billion in 1981, $14 billion in 1982, $18 billion in 1983, and $23 billion higher in 1984. If we were to continue this simulation farther into the future, we would find that the gap between GNP in the two simulations would continue to increase at approximately $5 billion per year--$28 billion in 1985, $33 billion in 1986, and so on.

As greater productivity is translated into higher demand, we find that the economy can produce more goods and services with the same amount of labor. This has two beneficial effects. First, unit labor costs decline, hence lowering prices. Second, lower prices enable consumers to purchase more goods and services with their income, hence leading to further increases in output and employment.

We find that the consumer price index grows at a slower rate with higher NASA R & D spending than without, and is a full 2% lower by 1984 than would otherwise be the case. Once again, this change does not occur in the early years of the simulation, but begins to become important in 1980.

One of the major effects of the higher level of real GNP and aggregate demand is the reduction in the unemployment rate of 0.4% by 1984. Since the labor force will be approximately 100 million strong by that date, this indicates, as a first approximation, an increase of 400,000 jobs. However, if we take into account the increase in the size of the labor force, the total will rise to 0.8 million new jobs. The increase in the labor force will occur for three principal reasons. First, the derived demand for labor will be greater because the marginal productivity of labor has increased. Second, the

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supply of labor will rise because the real wage has increased. Third, and probably most important, the increase in aggregate demand will reduce the amount of hidden unemployment as more entrants join the labor force.

It is also important to note that labor productivity rises substantially as a result of the increased NASA R & D spending. The index of labor productivity for the private nonfarm sector grows at a rate of 2.75% during the 1980-1984 period, compared to an average annual rise of 2.40% with no increase in spending. By 1984 the level of labor productivity is 2.0% higher than the baseline projection.

Further details and comparisons are given in Table 6 for a $1 billion increase in NASA R & D spending. We also calculated alternative runs for $0.5 and $0.1 billion and found that the results were approximately linear for other levels of spending change of equal or smaller magnitude. Similarly a decrease in NASA R & D spending of $1 billion would have reverse effects of the same magnitude on economic activity.

Significance and Reliability of Findings

Significance of Findings

One does not need an econometric model to show that an increase in government spending will raise GNP and lower unemployment. We learned many years ago that it is easy to spend our way out of a recession if no other constraints are involved. Yet having just recently come from the realm of double-digit inflation and the first postwar decline in labor productivity,

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it is clear that alternative policies must be examined not only from the point of view of their effect on demand and employment but on the real growth rate and the rate of inflation as well.

NASA R & D spending increases the rate of technological change and reduces the rate of inflation for two reasons. First, in the short run, it redistributes demand in the direction of the high-technology industries, thus improving aggregate producitivty in the economy. As a result, NASA R & D spending tends to be more stabilizing in a recovery period than general government spending.

Second, in the long run, it expands the production possibility frontier of the economy by increasing the rate of technological progress. This improves labor productivity further, which results in lower unit labor costs and hence lower prices. A slower rate of inflation leads in turn to a more rapid rise in real dispoable income permitting consumers to purchase the additional goods and services being produced and generating greater employment.

In assessing these results, we once again stress the importance of distinguishing between demand and supply effects. A $1 billion increase in NASA spending will have an immediate effect on real GNP, raising it approximately $2.1 billion the first year and $2.5 billion the second year. These demand multiplier effects are not markedly different than those which would have occurred for a similar increase in other purchases of goods and services by the government sector or for release of funds to the private sector for construction projects. They are, however, substantially higher than the effects which would be obtained from a $1 billion increase in transfer payments or low-productivity jobs programs. In particular we have found that the demand multiplier is smallest and the increase in inflation is largest for a

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unit change in transfer payments. When we turn to the supply side, however, the multiplier effects of lowering prices and increasing real income are more than twice as large. Other government spending programs which do not expand the production possibility frontier and improve productivity have no additional effect on the economy after the initial increase in demand.

Reliability of Findings

The results found for the equation estimating γ are all in agreement with economic theory, as the signs and magnitude of the coefficients are within the range expected from a priori expectations. Similarly, the statistical results indicate a high degree of correlation and no bias in the regression coefficients, or the goodness-of-fit statistics or the standard errors of estimate. In addition, the results are in accord with the findings of other econometric studies. Nevertheless, a number of criticisms have been raised about the final equation for γ, suggesting that the results might be significantly different if relatively minor changes were made to the function. These suggested changes focus on three areas; the choice of γ_C (the CEA series) instead of γ_D (the Denison series), the inclusion of the Cp term by itself and in conjunction with ORD, and the exclusion of the indexes of labor quality, particularly the level of education. To test the validity of these suggestions, we calculated sixty regression equations, including a "least favorable" case which incorporated all of the above changes. The sample period fits are somewhat worse, indicating that γ_D contains a larger random component than γ_C, but the coefficient of the term for NASA R & D spending is similar for these regressions. Even the "least favorable" case does not change the general conclusions of the study concerning either the rate of return or the economic impact of changes in NASA R & D spending.

REPORT OF THE COMPTROLLER GENERAL OF THE UNITED STATES

NASA Report May Overstate The Economic Benefits Of Research And Development Spending

The National Aeronautics and Space Administration commissioned Chase Econometrics, Inc., to evaluate how spending on NASA research and development affects the U.S. economy. Chase's report concluded that many benefits resulted from such spending between 1960 and 1974.

GAO assessed the Chase study to determine whether it successfully estimated the benefits of NASA spending. The study does not prove convincingly that the benefits are as large as stated.

Reproduced from U.S. General Accounting Office. NASA report may overstate the economic benefits of research and development spending. Washington, G.A.O., 1977. 53 p.

PAD 78-18

OCTOBER 18, 1977

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-164912

The Honorable William Proxmire
Chairman, Subcommittee on
HUD-Independent Agencies
Committee on Appropriations
United States Senate

Dear Mr. Chairman:

Pursuant to your request of September 15, 1976, we have prepared an independent assessment of the NASA-commissioned report entitled "The Economic Impact of NASA R&D Spending," issued by Chase Econometrics, Inc. In May 1977, we sent you a draft copy of our report to assist you in your appropriations hearings. Our final report presents the same assessment along with NASA's and Chase's comments. In general, both agreed with our conclusions.

As agreed with your office, we expect to release the report to the public in about 7 days.

Sincerely yours,

Elmer B. Staats

Comptroller General
of the United States

REPORT OF THE
COMPTROLLER GENERAL
OF THE UNITED STATES

NASA REPORT MAY OVERSTATE THE ECONOMIC BENEFITS OF RESEARCH AND DEVELOPMENT SPENDING

D I G E S T

The National Aeronautics and Space Administration (NASA) contracted with Chase Econometrics Associates, Inc., to evaluate how Government research and development spending, particularly NASA's, affects the U.S. economy.

Chase's report "The Economic Impact of NASA R&D Spending" concluded that this spending produced many benefits between 1960 and 1974. The study did not try to evaluate how effectively NASA carried out its primary objectives, such as space exploration and satellite communication. NASA cited the Chase study in its 1976 appropriations hearings as evidence of certain beneficial effects of research and development.

The Chase study does not prove convincingly that the benefits are as large as stated. The study is useful as exploratory research, but other types of studies are necessary to provide a complete evaluation of NASA research and development.

The most significant conclusion of the Chase study is that "* * * a $1 billion sustained increase in NASA R&D spending will raise real GNP $23 billion by 1984 * * *." Of this estimated increase, $21 billion would result from improved technology and productivity, and the rest would result from increased Government spending, which stimulates spending in different parts of the economy.

Since similar increases would result from Government spending on other projects, such as welfare programs, the "multiplier effects" alone do not justify more NASA research and development spending. For this reason, GAO focused on projected technological improvements.

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RECOMMENDATION TO THE ADMINISTRATOR OF NASA

Future evaluation studies should look at specific innovations, their effect on specific industries, and the process by which NASA expenditures for research and development improve productivity in the economy. In other words, some of the more important innovations, rather than the total budget, could be examined, and individual technological improvements in individual industries, rather than gross national product figures, could be studied. GAO believes that such studies would give the Congress a more accurate picture of what taxpayers are getting for their money.

MATTER FOR CONSIDERATION BY THE CONGRESS

Technical studies are frequently presented to the Congress in support of agency budgets and as evidence for or against proposed legislation. When important questions are at stake, such studies should be subjected to independent examination and appraisal.

AGENCY COMMENTS

In general, NASA as well as Chase Econometrics, Inc., agreed with our assessment of the Chase report. (See ch. 5.)

The Chase conclusions are questionable from three points of view:

--The results, even if accepted as accurate, do not provide the type of information needed to determine whether NASA's spending should increase or decrease. The estimates are of average, rather than incremental, effects. Therefore they do not show whether more spending for research and development would result in as many benefits as before. Within NASA's budget, the most productive or unproductive projects or types of spending have not been spelled out.

--Even if the Chase approach is accepted, the techniques used had certain shortcomings. Plausible and seemingly minor changes in the study's assumptions lead to major changes in the results. Under some of these alternatives, NASA research and development seemed to have no great effect on productivity. Such sensitivity to small changes in methodology indicates considerable uncertainty in Chase's results.

--Basically, the results depend upon statistical correlation between NASA research and development spending and changes in a measure of gross productivity in the U.S. economy. No information on specific NASA projects or on the adoption of new techniques by private business is used in the study. Because of problems in measuring total productivity in the economy and because other possible causes of technological progress were ignored, the correlations may not indicate a true cause-and-effect relationship.

Although the methodology of a particular study may be questioned, the importance of evaluating NASA's programs is undiminished. NASA has clearly been an important source of technical progress in recent years.

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ABBREVIATIONS

GAO	General Accounting Office
GNP	gross national product
NASA	National Aeronautics and Space Administration
R&D	research and development

CHAPTER 1

INTRODUCTION

The National Aeronautics and Space Administration (NASA) spent about $40 billion on research and development (R&D) between 1961 and 1974. This represented 12 percent of total R&D spending in the United States during that period. Realizing that NASA's research findings could have wide application throughout the economy, the Congress directed NASA to "* * * provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

NASA's findings have had countless applications--in cardiac pacemakers, insulation materials, integrated circuits, gas turbines, and many more. Little is known, however, of the magnitude of these "spinoff" benefits to the economy. Chase Econometrics, Inc., prepared a report "The Economic Impact of NASA R&D Spending" for NASA evaluating these effects. The report concluded that NASA has a very favorable impact on the economy.

We were requested to "* * * evaluate the appropriateness of the study's assumptions, its analytical techniques, and the validity of its conclusions."

SCOPE OF REVIEW

In making this review, we

--analyzed the Chase report and, for background, some other NASA studies of R&D spillovers;

--replicated some of the statistical analysis of the Chase report to obtain certain measures of statistical significance and to see how sensitive the conclusions would be to changes in the basic assumptions; and

--discussed the report with NASA and Chase officials, and several other experts on the economics of R&D.

CHAPTER 2

THE PROBLEM OF R&D EVALUATION AND HOW THE CHASE REPORT TRIES TO SOLVE IT

THE PROBLEM OF EVALUATING GOVERNMENT-SPONSORED R&D

The Federal Government finances research and development in addition to that carried out by the private sector. The usual reasons for private R&D spending are future sales and profitability. Private firms tend to ignore benefits that would accrue to other firms (unless they can receive royalties) or to society as a whole. These are known as "spillover" benefits. Also, private firms may emphasize projects with short-term payoffs. Additional R&D spending by NASA or other government agencies, it is argued, could provide benefits to the Nation in excess of costs and thereby in some sense increase total benefits to society.

This analysis is similar to that supporting government regulation of pollution--an individual firm may fail to consider the harmful results of its activities if it does not have to bear the costs. Society may benefit by inducing the firm to reduce the pollution it causes. The R&D argument is the other side of the coin--that the government can increase benefits to society by inducing the firm to carry out more R&D or by doing the R&D itself.

The above argument for government involvement is valid, but it leaves the practical problem of deciding how much and what type of R&D to sponsor. First, the benefits that can be expected from the R&D must be estimated. There are many types of benefits--new products, greater productivity, lower costs--all of which are difficult to measure. Similarly, there are many types of R&D--such as medical, aerospace, and electronic--and analysis of aggregate R&D may not be very helpful to government decisions in specific sectors. In any case, predicting the results of any particular research activity is difficult. Examining the results of past programs may suggest productive new R&D ventures, but it will not provide exact measurements of future benefits.

WHAT THE CHASE REPORT SAYS

The Chase study has three main parts corresponding to the types of economic impact of R&D spending.

Section 2: Short-term economic impact. The NASA spending is directed toward certain high-technology industries and naturally affects them more than other parts of the economy. There are also short-term "multiplier" effects of the spending. Chase reports that keeping the Federal budget constant, while shifting more dollars to NASA, would cause the gross national product (GNP) to increase slightly as the dollars spent move through the economy.

Section 3: Long-run economic impact. The Chase study says that NASA R&D spending affects technological progress and results in higher productivity in the economy.

Section 4: Macroeconomic impacts. Here, the estimated improvements in productivity plus the multiplier effects of hypothetical higher NASA spending are analyzed together, using the Chase Econometrics Macro model to estimate effects on GNP, inflation, unemployment, etc. The study concludes that "* * * a $1 billion sustained increase in NASA R&D spending will raise real GNP $23 billion by 1984 * * *." Of this estimated increase, $21 billion comes from technological progress and $2 billion comes from multiplier effects of increased government spending.

The results in section 2 are, in our judgment, reasonable estimates, in accord with widely accepted economic analysis. These effects are small, however, and they are not "benefits" in the strictest sense. Rather, they are measures of induced increases in the level of economic activity. As such, they are not crucial to deciding whether more or less money should be spent on NASA R&D, because similar effects could be obtained by other forms of government spending--such as defense procurement or energy R&D. Tax cuts are, of course, a comparable alternative, although the size of their impact may differ. Because the results in section 2 are not particularly controversial or critical to budgetary decisions, we do not discuss them further in this report.

The results in section 4 depend upon section 3, but they are basically elaborations of the macroeconomic effects of section 2.

Section 3 is the heart of the Chase report because it estimates economic benefits (in the form of increased productivity) as opposed to impacts on the economy (which may be neutral rather than beneficial). Government spending for certain goods causes some industries to grow in relation to other industries. Policymakers should be aware of such

impacts, but such impacts are not necessarily a worthy goal of government policy. On the other hand, increased productivity in the economy is clearly beneficial. Therefore, the remainder of our report deals with this important topic.

HOW THE CHASE REPORT REACHED THESE CONCLUSIONS

Chase Econometrics attempted to test the theory that NASA R&D (among other factors) affects the rate of technological progress in the U.S. economy. Testing this theory requires a measure of technological change, a subject on which considerable research has been done. The Chase study uses a productivity measure based on a data series for "potential" GNP developed by the Council of Economic Advisors. Potential GNP is that which could be achieved if all labor and capital were fully employed. Potential GNP has grown steadily over the years, partly because of increases in the available quantities of labor and capital. The rest of the growth of potential GNP is the result of improvements in productivity; that is, growth in the level of output per unit of input. The statistical measure of productivity growth is a residual factor--it represents increases in potential GNP not due to increases in the available quantities of labor and capital.

The next part of the theory is that increases in productivity result from several explanatory variables:

--NASA R&D expenditure as a percentage of GNP.

--Other R&D expenditures as a percentage of GNP.

--An index of "industry mix" to measure the effect of different rates of technological growth in different industries.

--An index of labor quality (for which no significant statistical effect could be identified).

--An index of capacity utilization.

The Chase hypothesis is that if this theory is true (that these variables affect technological progress), then an empirical test of the theory would yield statistically significant results. That is, there will be a statistical pattern of correlation between the "causes" and the "effect."

It is logical to assume that R&D will not affect technological progress as soon as the R&D money is spent, but

will have a delayed effect spread over several years. Chase uses statistical methods intended to allow for this delayed effect.

Within this theoretical framework, there are many possible variations in statistical testing. For example, variables can be measured in different ways, data from different time periods can be used, and variables can be added, left out, or combined in different ways. Chase experimented with many of these variations, finally selecting a statistically estimated equation that Chase believed best expressed the underlying theoretical considerations. Chase's "preferred" equation supported the theory that NASA R&D has had a significant effect on technological progress.

CHAPTER 3

CRITIQUE OF THE STUDY'S STATISTICAL FINDINGS

Even if the Chase Econometrics approach is accepted, certain statistical problems cast doubt on the results. In replicating the statistical analysis, we found that plausible and seemingly minor changes in the study's assumptions led to significant changes in the results. (See app. II for details.) Under some of these alternative assumptions, NASA R&D apparently had no significant effect on productivity. Here, as throughout this report, we take no position on the actual magnitude of NASA's impact. The point is that the great sensitivity of the Chase report results to small changes in methodology indicates considerable uncertainty in the Chase conclusions. We believe that the findings should be insensitive to slight changes in the methodology.

The key number in the Chase conclusions is the estimated coefficient of NASA R&D spending--the "NASA effect." In Chase's "preferred equation," this figure is estimated to be 0.426. Chase's interpretation is that a $1 billion increase in NASA R&D spending would eventually increase the total capacity of the U.S. economy by $4.26 billion. Another interpretation by Chase is that this represents a 43-percent rate of return on investment in NASA R&D.

This conclusion, if accepted, would indicate an enormous impact on the economy. The literal interpretation is that, if NASA had spent nothing on R&D, productivity would have declined in the United States between 1965 and 1974. That is, NASA R&D is given credit for all of the Nation's productivity growth, and more besides.

Minor alterations in the Chase techniques, however, lead to lower estimated values for the NASA effect. In some cases, the estimated value of the key coefficient is not much above zero, which would indicate no discernible impact.

To investigate the sensitivity of the Chase results to changes in some of the statistical assumptions, we replicated the Chase statistical analysis. Using the same data and the same basic statistical techniques, we estimated several different regression equations that we believed to be as plausible as or more plausible than Chase's preferred equation. (See app. II.)

Our results are summarized as follows:

1. Chase's preferred equation uses data from 1960 to 1974. If data from 1956 to 1974 were used, the estimate of the effect of NASA R&D drops 25 percent to 0.318.

In general, using the longer period is preferable because the larger the sample, the smaller the likelihood of spurious correlation. The Chase report prefers the shorter period because NASA R&D spending was negligible from 1956 to 1959.

We believe that including a period in which NASA spending was negligible is advantageous because this gives a wider range of values to NASA R&D spending. To see why this is worthwhile, consider the opposite case: If NASA R&D had been exactly, say, $2 billion each year for 10 years, an examination of data for that period would yield no information on the effect of changes in NASA R&D, for no changes would have occurred. Only by including a variety of values in the sample can the cause-and-effect relationship be observed and measured.

2. The Chase report makes certain adjustments for the level of capacity utilization in the economy. Alternative adjustments, which we consider superior, cause significant changes in the main results.

3. Chase's preferred equation does not include changes in labor quality as a possible influence on productivity. The Chase report noted that variables representing labor quality did not significantly affect productivity. We believe that labor quality should be considered in the statistical estimation procedures. If it had, the estimate of the "NASA effect" would have been about 33 percent lower for 1960-74 and 16 percent lower for 1956-74.

4. When we incorporate all of the changes we believe to be improvements, the estimated value of the NASA R&D coefficient drops to 0.136--a figure less than a third as large as Chase's estimate. Furthermore, the statistical measure of significance falls to a level that can be interpreted as "insignificant." That is, in our equation the observed relation between NASA R&D and productivity growth is indistinguishable from a relation that might be observed by chance between two unrelated data series.

We emphasize that this is not "proof" that NASA R&D has no effect on productivity. But such findings cast doubt on the Chase methodology.

5. Finally, the Chase results may be questioned because of a statistical problem called "multicollinearity." This problem occurs when two variables that are supposed to affect the dependent variable (in this case "productivity") are closely correlated. In such a case, distinguishing between the separate effects of the two variables is difficult. In fact, NASA R&D is highly correlated with other R&D expenditures between 1960 and 1974. This correlation casts doubt on the accuracy of the estimate of the NASA effect; it is also largely responsible for the sensitivity of the estimates to slight changes in the assumptions.

In statistical work of this type, there are many possible alternative assumptions. We reestimated the Chase equation making certain changes that we considered improvements to the Chase approach. Our estimate of the "NASA effect" was considerably lower than that of the Chase study. Such results do not, in any sense, prove that the NASA effect is zero; they merely fail to identify such an effect.

At this stage, it is well to repeat that we believe that NASA has had certain beneficial effects on the economy, but that such effects are not well measured by the Chase method.

CONCLUSION

The results of the Chase study are sensitive to plausible and minor changes in the methodology. Under some assumptions, it could be concluded that NASA R&D had no significant effect. We, therefore, conclude that the Chase study does not sufficiently substantiate its findings on the effect of NASA R&D on productivity.

CHAPTER 4

CRITIQUE OF THE STUDY'S BASIC APPROACH

PROBLEMS WITH THE STUDY'S METHODS

The basic findings of the Chase Econometrics study depend upon statistical correlation between NASA R&D spending and changes in a measure of productivity for the entire economy. The data on these two variables shows that NASA R&D reached its highest levels in 1966-68 and that the highest rates of productivity change occurred in 1970-72. Since (in the Chase preferred equation) the data studied covers only 1960 to 1974, these two changes dominate the analysis and are responsible for the correlation discovered. Indeed, extending the analysis to include data from earlier years weakens the findings. Although this correlation may suggest a cause-and-effect relationship, it should not be interpreted as a precise measure of the NASA effect.

Figure 1 shows the basic data series that Chase worked with. (Other variables were also used in the analysis.) Productivity growth is explained mainly by NASA R&D and by other R&D, expressed as a percentage of GNP. As the graph shows, productivity growth has varied during the period illustrated. A main conclusion of the Chase study is the statistical correlation between NASA R&D and productivity growth. The two data series are virtually uncorrelated with each other, but this is plausible; it would probably take several years for R&D spending to affect productivity. Thus, Chase determined that the peak in productivity growth (1971) was caused by the peak in NASA R&D (around 1967).

The series on productivity growth has fluctuated irregularly for as long as the data has been available--over 60 years. In this broader context, how reasonable is it to ascribe the latest upsurge in productivity almost entirely to an increase in NASA R&D? As mentioned in chapter 3, including only 4 more years of data in the analysis reduced the estimated impact of NASA R&D by 25 percent.

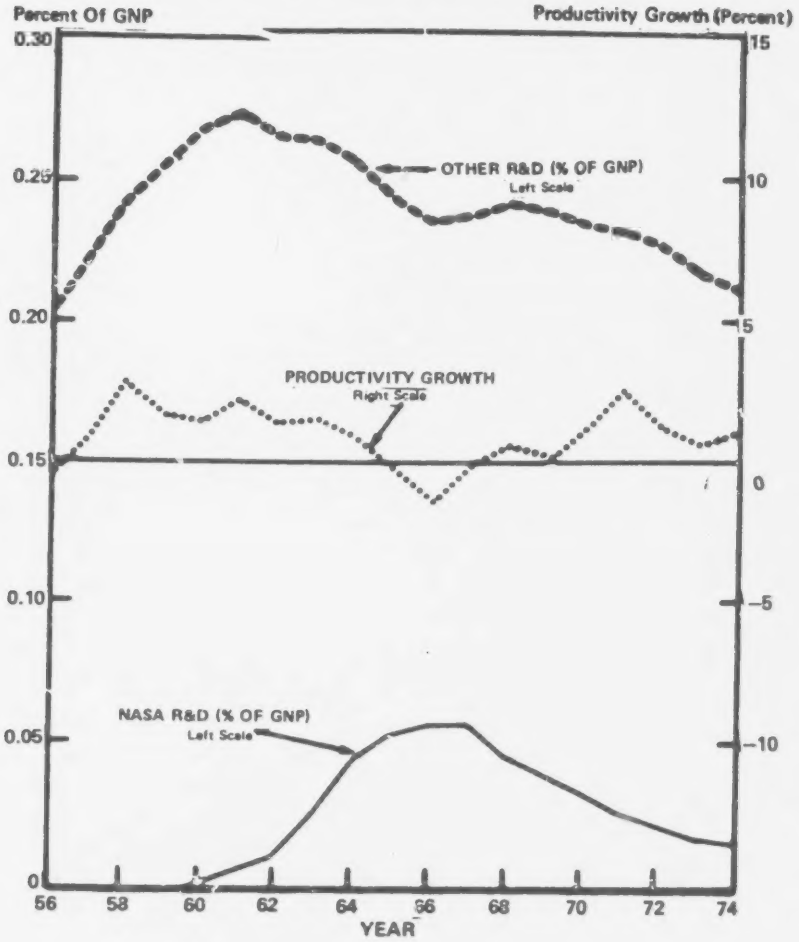
Figure 1 illustrates two more aspects of the basic data:

--NASA R&D is a small portion of total R&D--about 12 percent between 1961 and 1974. Yet this portion is held responsible for all of the productivity growth.

--Other R&D declined at about the same time that NASA R&D increased. This creates the statistical problem,

Figure 1

PRODUCTIVITY GROWTH
NASA R&D AND OTHER R&D
(AS DEFINED BY CHASE ECONOMETRICS)



mentioned in chapter 3, that makes it difficult to separate the effects of the two types of R&D.

In the Chase study, the main effect of NASA R&D is assumed to be raising the level of productivity in the economy; that is, increasing the total product (measured in dollars) that could be produced with available labor and capital. This does not directly measure the benefits resulting from improvements in products, except insofar as consumers demand fewer of the improved products and thereby release capital and labor to produce more of other products. Similarly, the value of new products is not well accounted for. If a new and better product replaces an old product that cost the same amount to produce, the GNP figures will not show the benefit. These criticisms of the Chase methodology point up inherent problems in using GNP as a measure of welfare.

The study does not use data on specific NASA projects or on the adoption of new techniques by the private sector. Rather, the data are on such an aggregate level that nothing about NASA is measured directly except its budget. More information, we believe, could have been used to advantage. As it is, the empirical work rests upon a theory--that more NASA R&D will cause more growth in productivity--which has little analytical support. Economists who have reviewed the study have asserted that the process of technological change is considerably more complex than the Chase study implicitly assumes.

USEFULNESS OF THE STUDY'S RESULTS

Granted that the Chase study has merit as exploratory economic research, how useful are its results to the budget process? Do the study's results, even if accepted as accurate, provide the information needed to determine whether NASA's budget should increase or decrease?

Any government program that produces a 43-percent rate of return would certainly be worth continuing. This greatly exceeds the average rate of return in the private sector. Still, the occurrence of past spinoffs does not insure that future spinoffs will occur at the same rate as new and different R&D projects are sponsored. New projects would still have to be justified on their own merits.

Two aspects of the Chase approach should be noted. First, the estimates of NASA's effect are average, rather than incremental, amounts. Even if it is granted that NASA's spending in 1965, for example, produced certain benefits, it

does not follow that increasing that year's budget by, say 20 percent, would have increased the benefits by 20 percent. More likely, the increase in benefits would have been less than 20 percent.

In any year, NASA considers many possible R&D projects. If NASA pursues those it judges to be the most productive, then increasing its budget would allow it to pursue one or more of those projects that it had previously rejected as below average in prospective payoff. To state the same principle of "diminishing returns" somewhat differently, it is likewise possible that, even in a year when NASA's projects produced great benefits, a few unproductive projects could have been eliminated, thereby reducing the budget without reducing benefits.

In any case, efficient budget management requires project-by-project evaluation. Whatever the merits of an overview of the impact of the entire agency budget, such an approach misses this necessary detail.

Second, when discussing the usefulness of this approach, one should keep in mind that much of the Chase report was devoted to macroeconomic and interindustry impacts of NASA R&D spending. Any form of government spending produces some such effects, and the differences among these effects are not crucial to allocating public funds to a particular agency.

IN DEFENSE OF THE CHASE METHOD

The merits of the Chase approach stand out more clearly when the alternatives are considered. Studying the effect of NASA R&D on a totally disaggregate basis involves many problems:

--Assessing the impact of every NASA R&D contribution would be prohibitively expensive, but choosing just a few would not necessarily give an accurate picture.

--Major technical innovations are spread through many segments of the economy and their effects are not felt for several years. It is doubtful that all of the effects could be accounted for in studies of individual projects.

The Chase approach at least attempts to measure the diffuse effects, although not with total success. The Chase study is not a definitive budget justification, but it is a worthwhile exploratory approach to a difficult problem in economics.

We believe that some compromise is possible between the Chase approach and the project-by-project approach. This would involve studying technical progress in the industries for which NASA R&D has been particularly important. NASA officials said some such studies are being considered.

RECOMMENDATION TO THE ADMINISTRATOR OF NASA

We recommend that the Administrator see that future evaluation studies take a less highly aggregated approach. That is, the researchers should

--analyze the process by which NASA R&D expenditures improve productivity in the economy;

--study some of the more important innovations, rather than the total R&D budget; and

--study individual technological improvements in particular industries, rather than GNP figures.

This kind of research would not produce a single measure of the total impact of all NASA R&D, like the $23 billion figure given by Chase. Indeed, accurate and meaningful aggregations of this kind may not even be feasible. But we believe that the results of a number of disaggregated studies would give the Congress a more accurate and informative picture of what taxpayers are receiving in return for their money.

MATTER FOR CONSIDERATION BY THE CONGRESS

Technical studies are frequently presented to Congress in support of agency budgets and as evidence for or against proposed legislation. We believe that, when important questions are at stake, such studies should be subjected to independent examination and appraisal.

CHAPTER 5

NASA AND CHASE COMMENTS AND OUR RESPONSE

We asked both NASA and Chase Econometrics to comment on our report. In general, both agreed with our conclusions. (See apps. III and IV.)

Some NASA comments leave the impression that our objection was merely over which of the alternative estimates is the most acceptable and that the estimate we chose still shows a high rate of return to NASA R&D spending. This is, however, not our point.

The logic of our analysis is as follows:

--In chapter 4, we argue that the approach taken by Chase will not answer the basic questions. Productivity is a complicated function of so many variables, current and lagged, that explaining it by a few variables will not provide meaningful information on cause-and-effect relationships. We doubt whether statistical investigations of time series data on GNP will ever measure the relation between R&D spending and productivity with the precision sought by the Chase study.

--In chapter 3, we assume, for the sake of argument, that the approach taken by Chase is acceptable. We conclude that minor respecification of Chase's preferred equation to produce a more plausible model results in a lower rate of return for NASA R&D on the one hand, and the possibility of no NASA productivity effect on the other. In NASA's words, "the variables selected may statistically interact to cloud the validity of the results." With the Chase result (a 43-percent rate of return), this is clearly the case. Though the validity of our result (a 28-percent rate of return) does not suffer from this particular statistical deficiency, it should not be taken at face value either, for reasons cited in this report.

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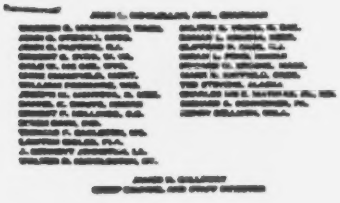
APPENDIX I



United States Senate

COMMITTEE ON APPROPRIATIONS
WASHINGTON, D.C. 20510

September 15, 1976

Honorable Elmer Staats
Comptroller General of the United States
General Accounting Office
441 G Street, N. W.
Washington, D. C. 20548

Dear Elmer:

At the Appropriation hearings for fiscal 1977, before the Subcommittee on Housing and Urban Development and Independent Agencies of the Committee on Appropriations, NASA presented to the Subcommittee, in support of its budget request, a study entitled: "The Economic Impact of NASA R&D Spending." This study, commissioned by NASA and performed by Chase Econometrics, Inc., concluded that NASA R&D spending has a substantial beneficial impact on the economy.

Although we find this study a useful input to our hearings, we would like the GAO to make a careful assessment of that study. This would give the members of the Subcommittee an independent view of the impact of NASA functions on the economy.

In your assessment of the study, we would like the GAO to evaluate the appropriateness of the study's assumptions, its analytical techniques, and the validity of its conclusions.

For your report to be timely, we would like to have it available to the Subcommittee before its Appropriations hearings that will be held in February or March of 1977. While NASA comments might be useful, the process of obtaining them should not delay the completion of the report beyond the time that it is needed. If you have any questions concerning this request, please contact Mr. Thomas van der Voort of my staff.

Sincerely yours,

William Proxmire, Chairman
HUD-Independent Agencies Subcommittee
Senate Appropriations Committee

WP:tvk

TECHNICAL APPENDIX TO CHAPTER 3

The Chase Econometrics "preferred equation" was one of many equations which were devised to determine the contribution of NASA R&D expenditures to the rate of technological change. The coefficient estimates which Chase produced from these equations may be found in table 3.13 on pages 87 and 88 of their report. Chase did not, however, present summary statistics of the range of error associated with coefficient estimates in alternative equation forms. These statistics describe the range of variability of the coefficient estimates and measure the range within which the true measure of the effect probably lies. The range of error associated with the Chase estimates of NASA R&D productivity effects in alternative equation forms is particularly important in view of the report's conclusions. We reproduced Chase's methodology in order to determine the range of error associated with coefficient estimates for NASA R&D in alternative equation forms that we believe are more plausible on both economic and statistical grounds.

Our reproduction of the Chase methodology should not be construed as an endorsement of a macroeconomic approach to measuring NASA-induced productivity changes. We are simply examining the following problem: If a macroeconomic approach is acceptable, how reliable are the estimates of the NASA contribution to the rate of technological change and how sensitive are these estimates to minor respecification of equations or variables that produce a more plausible model.

VARIABLES USED BY CHASE ECONOMETRICS

Chase used the following variables as proxies for the rate of technological change and for theoretical influences.

Dependent variable

Gamma - Council of Economic Advisors rate of technological change based on trend, adjusted for full employment of labor and capital resources.

Independent variables

NRDA - Almon weighted ratio of NASA R&D expenditures to GNP.

ORDA - Almon weighted ratio of other R&D expenditures to GNP.

ORDC - Almon weighted ratio of other R&D expenditures to GNP, weighted by a standardized measure of capacity underutilization.

IM-$\overline{IM}$ - Deviations of a Chase-designed industry mix variable from its mean. This variable is intended to account for resource shifts from low-technology to high-technology industries and vice versa.

CP-$\overline{CP}$ - Deviations of the Chase index of capacity utilization from its mean.

ΔIE - First differences in an index of labor quality as affected by education.

ΔIAS - First differences in an index of labor quality as affected by age-sex mix of the labor force.

Chase measured these variables over a period from 1956 to 1974. They were intended to measure five categories of influences on the rate of technological change, including (1) labor quality, (2) utilization of productive factors, (3) resource transfers which, when incorporated in high-technology industries, may be expected to increase the rate of technological change, (4) R&D expenditures, and (5) a dynamic or lagged response of the rate of technological change to increases in R&D expenditures. These determinants seem sound on theoretical grounds and may include all possible determinants.

RESULTS

Chase's preferred equation estimates the contribution of NASA R&D expenditures to the rate of technological change, includes the capacity weighted other R&D variable (ORDC), omits labor quality proxies (ΔIE and ΔIAS), and includes only observations for 1960 to 1974.

We believe that a more theoretically justifiable equation for measuring NASA-induced productivity changes would include labor quality proxies, an unweighted measure of other R&D expenditures (ORD), since the capacity transformation of this variable (ORDC) is questionable and leads to very complex interpretation of results. Also, we used observations for 1956 to 1974.

Our results are presented in table 2. The Chase results for the Chase preferred equation and for our preferred equation are presented as equations 1 through 4. These results are followed by our estimates of those same four equations (equations 5 through 9). Comparison of our results with Chase's results shows that we have very closely reproduced its methodology for both sample periods.

Choice of sampling period

Correlation matrices for the variables we used in each sample period are presented in table 1. The correlation coefficient between the R&D variables that Chase employs in its preferred equation for 1960 to 1974 is very high (0.817). When collinearity is this high between two variables, sorting out the separate effects of each is impossible. Because of this, the coefficient estimates that Chase presents in table 3.13 of its report are very sensitive to minor alterations in variable or equation form. The correlation coefficient between NRDA and ORDC is, however, only 0.267 for 1956-74, well within the range of acceptability. In comparisons of the matrices for each sampling period, the correlation coefficients between the critical pairings of R&D variables and between R&D variables and other included variables are more often lower over the longer sample period. The correlation coefficient for NRDA and ORDA is higher during 1956 to 1974 than during 1960 to 1974, but it is within an acceptable range. For these reasons, the longer sample period is preferred, particularly for estimating Chase's preferred equation.

Labor quality and other influences

In our preferred equation, NASA R&D enters without statistical significance for either sampling period. The coefficient on the other R&D variable is statistically significant for our preferred sampling period. When the Chase preferred equation for 1960-74 is altered only by substitution of a noncapacity weighted other R&D variable for the one Chase prefers, the coefficient on NASA R&D drops from 0.428 to 0.259 for 1960-74 and from 0.318 to 0.227 for the longer sampling period. The NASA coefficient remains statistically significant for both periods, however (equations 9 and 11). But the introduction of labor quality into these equations, though itself insignificant, causes the NASA coefficient to become statistically insignificant (equations 7 and 8).

Table 1

Correlation Matrices

1956-74

	GAMMA	NRDA	ORDC	ORDA	IMD	CPD	Δ IE	Δ IAS
GAMMA	1.000							
NRDA	-.0085	1.000						
ORDC	-.2745	-.2670	1.000					
ORDA	-.3259	.5272	.6487	1.000				
IMD	.6810	-.6646	-.0185	-.5988	1.000			
CPD	-.7964	.1537	.6187	.6771	-.6220	1.000		
Δ IE	-.0972	.2046	.0736	-.0560	-.1678	.2704	1.000	
Δ IAS	.4110	.1517	-.0452	.0237	.1718	-.1528	-.1052	1.000

1960-74

	GAMMA	NRDA	ORDC	ORDA	IMD	CPD	Δ IE	Δ IAS
GAMMA	1.000							
NRDA	.0819	1.000						
ORDC	-.3445	-.8170	1.000					
ORDA	-.6285	.2959	.2270	1.000				
IMD	.6588	-.6259	.2706	-.7506	1.000			
CPD	-.8388	-.1219	.5284	.6997	-.5119	1.000		
Δ IE	-.0963	.1769	.0093	-.0855	-.1499	.2814	1.000	
Δ IAS	.6192	.1876	-.1018	.0024	.2540	-.3873	-.1207	1.000

APPENDIX II

When labor quality proxies are introduced into an equation which is in all other respects similar to the Chase preferred equation, the coefficient on the NASA R&D variable becomes insignificant for 1960-74 (equation 10) but remains significant during the longer sampling period (equation 12). The result for 1960-74 is caused by the instability of the NASA R&D coefficient which results from the high intercorrelation between the preferred NASA and other R&D variables during that period.

We reemphasize that our preferred equation is equation 8. Labor quality is included and, thus, the equation contains all Chase proxies for theoretical influences. Capacity utilization enters "on its own" and not combined with an obscure transformation of the other R&D variable. In this equation, the NASA effect is insignificant.

CONCLUSION

The Chase results are sensitive to both the manner in which the estimating equations are specified, the sample periods, and the manner in which R&D variables are measured. If NASA R&D spending has as strong an effect as the Chase study claims, then that effect should not be greatly altered in a more fully specified and more theoretically defensible equation.

Table 2

Coefficient Estimates and Summary Statistics

Chase results	Const.	NRDA	ORDA	ORDC	IM-$\overline{IM}$	CP-$\overline{CP}$	ΔIE	ΔIAS	$-2\bar{R}$	D.W.	S_e	Eq. No.
Chase Pref	-1.81	(.426)		.074	.031	-.157			.883	1.95	?	1
1960-74	(?)	(3.9)		(2.0)	(4.5)	(3.1)						
Chase Pref	-.94	.318		.046	.029	-.158			.883	1.94	?	2
1956-74	(?)	(5.4)		(2.4)	(4.3)	(3.7)						
GAO Pref	?	.179	.080		.029	-.140	.072	2.09	.88	?	?	3
1960-74	(?)	(?)	(?)		(?)	(?)	(?)	(?)				
GAO Pref	?	.135	.087		.026	-.177	.096	1.97	.90	?	?	4
1956-74	(?)	(?)	(?)		(?)	(?)	(?)	(?)	(?)			
GAO results												
Chase Pref	-1.74	.428		.074	.031	-.157			.885	1.96	.34	5
1960-74	(1.52)	(3.96)		(2.04)	(4.52)	(3.18)						
Chase Pref	-.60	.318		.046	.029	-.158			.884	1.95	.36	6
1956-74	(1.33)	(5.45)		(2.40)	(4.36)	(3.77)						
GAO Pref	-1.46	.178	.081		.029	-.140	.072	2.09	.877	1.80	.35	7
1960-74	(.52)	(2.03)	(.67)		(2.95)	(2.05)	(.90)	(1.18)				
GAO Pref	-1.48	.136	.087		.026	-.177	.096	1.97	.897	1.72	.34	8
1956-74	(2.21)	(1.73)	(2.73)		(3.97)	(4.24)	(1.57)	(1.82)				
ALT	-1.83	.259	.102		.037	-.124			.862	1.75	.38	9
1960-74	(1.00)	(3.26)	(1.32)		(4.43)	(2.58)						
ALT	- .71	.287		.037	.027	-.134	.029	2.04	.879	1.83	.35	10
1960-74	(.49)	(1.79)		(.78)	(3.26)	(2.32)	(.47)	(1.21)				
ALT	- .89	.227	.067		.033	-.139			.876	1.83	.37	11
1956-74	(1.38)	(3.14)	(2.11)		(5.13)	(3.53)						
ALT	- .79	.269		.047	.024	-.173	.048	1.77	.891	1.70	.35	12
1956-74	(1.71)	(4.20)		(2.53)	(3.44)	(4.02)	(.83)	(1.59)				

APPENDIX II

 APPENDIX III

NASA
National Aeronautics and
Space Administration

Washington, D C
20546

July 11, 1977

Reply to Attn of W

Mr. R. W. Gutmann
Director
Procurement and Systems
Acquisition Division
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Gutmann:

Thank you for the opportunity to comment on the draft report entitled, "Review of 'The Economic Impact of NASA R&D Spending'," which was prepared by GAO's Program Analysis Division pursuant to a request of the Chairman, Subcommittee on HUD-Independent Agencies, Senate Committee on Appropriations.

NASA finds that the GAO analysis is well done and does not take issue with the results. The enclosure discusses the most important differences between the GAO analysis of the data used in this study and the Chase Econometrics analysis, which are based on the art of interpreting the statistical results.

Sincerely,

Kenneth R. Chapman
Assistant Administrator for
DOD and Interagency Affairs

Enclosure

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
COMMENTS ON THE GAO DRAFT REPORT
ENTITLED "REVIEW OF 'THE ECONOMIC
IMPACT OF NASA R&D SPENDING'"

The GAO finds that the Chase study does not:

- Provide information useful to budget makers which indicates the economic impacts of incremental changes in NASA R&D funding
- Present statistical results that are stable and accurate within acceptable levels of confidence
- Reveal a true cause and effect relationship between NASA funding and changes in total productivity

But the GAO recognizes and believes that:

- NASA has contributed significantly to the economic productivity of the nation
- The Chase study was valuable exploratory research into a difficult (and as yet) unsolved problem
- It would be valuable for NASA to continue doing economic evaluations of its programs, particularly at a more detailed industry and specific innovation level

The major methodological problem that the GAO had with the Chase study was the sensitivity of the results to relatively minor changes in the variables used for the regression analysis. With this in mind, they re-created the data base Chase used and re-ran the equations, testing for statistical significance.

The most important differences between the GAO analysis of the data used in this study and the Chase Econometrics analysis rest in the art of interpreting the statistical results. Chase chose a regression equation which when

analysed showed a 43 percent rate of return to NASA R&D funding. In their preferred equation the "NASA R&D" variable was statistically significant. The GAO chose an equation that included the greatest number of explanatory variables at the expense of the statistical reliability of the "NASA R&D" variable. They also used a longer time span which included a period without NASA spending as well as the period of heavy NASA funding which Chase had mainly emphasized. Interpreting the regression equation that the GAO prefers (which was one of the many equations Chase had analysed and rejected) yields a 28 percent rate of return to NASA R&D. This result is still well within a range of economic returns that can be considered very good investment of government R&D funds.

NASA accepts the GAO critique and its conclusions as being constructive, accurate, and objective. We agree that the data contain some inherent measurement problems and that the variables selected may statistically interact to cloud the validity of the results.

NASA recognizes that empirical measurement in economics is an inexact science and that the specific magnitude of the results of the Chase study is not as important a finding as the direction and the approximate range of returns. The GAO analysis does not change the basic conclusions of the Chase study. Their discussion tends to reinforce those conclusions since their data indicate that between 1966 and 1974 NASA has (when NASA funding was having its full effect) contributed to productivity about 26 percent as much as all other R&D combined. This can favorably be compared to the fact that NASA in those same years was funding only 12 percent of all of the R&D investment in the nation.

NASA agrees that the macroeconomic approach to economic evaluations of impacts has limitations. The GAO points these out, but also recognizes that the alternatives to providing similar policy conclusions are not feasible. They are also aware that the Chase approach is based on standard and supportable economic theory.

APPENDIX III

NASA finds that the GAO analysis is well done and does not take issue with their results. Their suggestions for further analysis have helped in the planning already underway within NASA for doing more detailed microeconomic and macroeconomic studies, which will improve on the past analyses.

Nathaniel B Cohen 7/7/77

Nathaniel B. Cohen
Director, Office of Policy Analysis

Date

Chase Econometric Associates, Inc.

a Subsidiary of The Chase Manhattan Bank, N.A.

555 City Line Avenue, Bala Cynwyd, Pennsylvania 19004 (215) 667-7360 Telex: 831809

June 14, 1977

Mr. Harry S. Havens
Director
Program Analysis Division
United States General Accounting Office
Washington, DC 20548

Dear Mr. Havens:

Thank you for your letter of June 1 and the accompanying draft of your report entitled "Review of 'The Economic Impact of NASA R&D Spending.'"

I have read your review and must say that I find it to be fair to all sides concerned. We did experiment with some 60 different regression equations and found that the critical coefficient of NASA R&D spending did not vary as much as you have indicated. However, I would certainly not rule out the fact that it is possible to choose other combinations of variables in that regression, although you did not list these specifically.

I appreciate your giving me the opportunity to review this draft.

Sincerely yours,

Michael K. Evans

Michael K. Evans

MKE:mhr

(97136)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Federal Funds

General and special funds:

RESEARCH AND DEVELOPMENT

For necessary expenses, not otherwise provided for, including research, development, operations, services, minor construction, maintenance, repair, rehabilitation and modification of real and personal property; tracking and data relay satellite services as authorized by law; purchase, hire, maintenance, and operation of other than administrative aircraft, necessary for the conduct and support of aeronautical and space research and development activities of the National Aeronautics and Space Administration; [and including not to exceed (1) $1,769,000,009 for Space Shuttle, (2) $1,796,000,000: *Provided*, That the amount available for obligation or expenditure shall be reduced to the extent subsequent authorizations provide for transfers for Space Flight Operations, (3) $115,000,000 for Space Transportation Systems—Upper Stages, (4) $88,000,000 for Space Transportation Systems Operations—Upper Stages, (5) $137,500,000 for the Space Telescope, (6) $34,500,000 for the Gamma Ray Observatory, (7) $92,600,000 for Project Galileo, (8) $4,000,000 for a Space Station, (9) $55,000,000 for Performance Augmentation, without the approval of the Committees on Appropriations, $5,542,800,000] *$5,708,500,000*, to remain available until September 30, [1984:] *1985*: [*Provided*, That $280,000,000 shall be made available for aeronautical research and technology, that $192,000,000 shall be made available for design, development, procurement, and other related requirements of liquid hydrogen-liquid oxygen upper stages (Centaur): *Provided further*, That none of the funds in this or any other Act shall be used for the development of a fifth space shuttle orbiter without the approval of the Committees on Appropriations:] *(42 U.S.C. 2451, et seq.; Department of Housing and Urban Development—Independent Agencies Appropriation Act, 1983, additional authorizing legislation to be proposed.)*

Program and Financing (in thousands of dollars)

Identification code 80-0108-0-1-999	Budget plan (amounts for research and development activity only)			Obligations		
	1982 actual	1983 est.	1984 est.	1982 actual	1983 est.	1984 est.
Program by activities:						
Direct program:						
1. Space transportation systems:						
(a) Capability development	2,638,350	2,144,100	1,927,400	2,543,285	2,262,315	1,944,400
(b) Operations	466,500	1,453,700	1,570,600	459,966	1,442,167	1,588,100
2. Scientific investigations in space:						
(a) Physics and astronomy	322,400	441,000	514,600	333,045	484,335	514,600
(b) Planetary exploration	210,000	186,400	205,400	198,037	208,663	205,400
(c) Life sciences	39,500	55,700	59,000	51,352	58,889	59,000
3. Space and terrestrial applications:						
(a) Space applications	324,300	351,000	289,000	318,983	397,618	289,000
(b) Technology utilization	8,000	17,000	4,000	8,083	10,191	4,000
4. Space research and technology	111,000	123,000	138,000	117,817	131,370	138,000
5. Aeronautical research and technology	264,800	280,000	300,300	258,357	312,678	300,300
6. Energy technology				−17	17	
7. Supporting activity: Tracking and data acquisition	402,100	498,900	700,200	382,573	532,562	700,200
Subtotal direct program	4,786,950	5,542,800	5,708,500	4,671,481	5,840,605	5,743,000
Program funded in R&PM	48,950					
Program funded in this account	4,738,000	5,542,800	5,708,500	4,671,481	5,840,605	5,743,000
Reimbursable program:						
1. Space transportation systems:						
(a) Capability development	177,680	245,250	211,500	159,464	283,112	211,500
(b) Operations	373,947	451,600	473,400	47,865	507,274	473,400
2. Scientific investigations in space:						
(a) Physics and astronomy	1,707	450	170	1,403	852	170
(b) Planetary exploration	155	50		176	174	
(c) Life sciences	196	170	170	191	174	170
3. Space and terrestrial applications:						
(a) Space applications	111,144	92,850	115,170	403,640	136,121	115,170
(b) Technology utilization	7,527	13,000	14,470	6,384	14,365	14,470
4. Space research and technology	5,062	1,450	1,250	4,971	1,680	1,250
5. Aeronautical research and technology	25,578	22,850	24,290	28,316	28,299	24,290
6. Energy technology	140,104	123,500	97,800	117,730	164,183	97,800
7. Supporting activity: Tracking and data acquisition	43,171	21,300	21,500	39,175	26,959	21,500
Total reimbursable program	886,271	972,470	959,720	809,315	1,163,193	959,720
10.00 Total obligations	5,624,271	6,515,270	6,668,220	5,480,796	7,003,798	6,702,720
Financing:						
Offsetting collections from:						
11.00 Federal funds	−594,346	−779,865	−761,255	−560,775	−779,865	−761,255
14.00 Non-Federal sources	−291,925	−192,605	−198,465	−291,701	−192,605	−198,465
Unobligated balance available, start of year: For completion of prior year budget plans						

Reproduced from The Budget of the United States, 1984--Appendix. Washington, G.P.O., 1984. p. I-T1--I-T8. (Document, House, 98th Congress, 1st session, no. 98-4)

General and special funds—Continued

RESEARCH AND DEVELOPMENT—Continued

Program and Financing (in thousands of dollars)—Continued

Identification code 80-0108-0-1-999	Budget plan (amounts for research and development actions programed)			Obligations		
	1982 actual	1983 est.	1984 est.	1982 actual	1983 est.	1984 est.
21.40 Direct				−282,483	−347,305	−34,500
21.40 Reimbursable				−147,696	−190,723	
23.40 Unobligated balance transferred to other accounts				1,200	15,000	
Unobligated balance available, end of year: For completion of prior year budget plans:						
24.40 Direct				347,305	34,500	
24.40 Reimbursable				190,723		
25.00 Unobligated balance lapsing				631		
39.00 **Budget authority**	**4,738,000**	**5,542,800**	**5,708,500**	**4,738,000**	**5,542,800**	**5,708,500**
Budget authority:						
40.00 Appropriation	4,740,900	5,542,800	5,708,500	4,740,900	5,542,800	5,708,500
41.00 Transferred to other accounts	−2,900			−2,900		
43.00 **Appropriation (adjusted)**	**4,738,000**	**5,542,800**	**5,708,500**	**4,738,000**	**5,542,800**	**5,708,500**
Relation of obligations to outlays:						
71.00 Obligations incurred, net				4,628,320	6,031,328	5,743,000
72.40 Obligated balance, start of year				1,267,945	1,096,699	1,793,027
74.40 Obligated balance, end of year				−1,096,699	−1,793,027	−1,931,027
77.00 Adjustments in expired accounts				−3,190		
90.00 Outlays				4,796,376	5,335,000	5,605,000

Status of Guaranteed Loans (in thousands of dollars)

	Position with respect to limitation on commitments:			
2112	Limitation on commitments: Loans by the FFB			
2132	Commitments exempt from limitation: Loans by the FFB	146,345	205,000	36,700
2152	New commitments, gross: Loans by the FFB	146,345	205,000	36,700
	Cumulative balance of guaranteed loans outstanding:			
2210	Outstanding, start of year	637,700	757,749	932,649
2231	Loans guaranteed: New loans guaranteed	146,345	205,000	36,700
2250	Repayments and prepayments	−26,296	−30,100	−176,700
2290	Outstanding, end of year	757,749	932,649	792,649
	MEMORANDUM			
2299	U.S. contingent liability for guaranteed loans outstanding, end of year	757,749	932,649	792,649
	Addendum: Federal Financing Bank transactions:			
	Direct loans made by the FFB and guaranteed by this account			
1410	Outstanding, start of year	637,700	757,749	932,649
1430	New loan disbursements	146,345	205,000	36,700
1450	Repayments	−26,296	−30,100	−176,700
1490	Outstanding, end of year	757,749	932,649	792,649

This appropriation provides for the following research, development, procurement and operations activities of the National Aeronautics and Space Administration:

1. *Space transportation systems (STS).*—The objectives of this activity are focused on production and operations of the Space Shuttle vehicle and other elements of a Space Transportation System. The elements of the program are described below along with work to be performed during 1984.

(a) *Space transportation capability development.*—The first reusable Earth-to-orbit vehicle is the key element in the Space Transportation System. The Shuttle has unique capabilities not available with expendable launch vehicles, including retrieval of satellites, experiments and equipment for reuse; maintenance and repair in orbit; and reuse of space laboratories. Cost effective operations of the Shuttle will allow increased versatility and productivity of space operations for all users.

In 1982, the Shuttle successfully completed the final two orbital flight tests of the four scheduled in the development program and was declared operational by the President on July 4, 1982. The Shuttle's actual flight performance fulfilled the hopes and expectations of its designers. In spite of minor technical problems which were to be expected during the developmental phase, the overall system worked extraordinarily well. The first operational flight was successfully flown in November 1982.

The second orbiter, Challenger, was delivered on schedule in July 1982 to the Kennedy Space Center. The fabrication of the third and fourth orbiters—Discovery and Atlantis—is underway, and these orbiters will be delivered in late 1983 and late 1984, respectively. In 1984, the principal activities to be conducted in Shuttle Production and Capability Development, in addition to production of the flight orbiters are: testing of the main engine for continuing operations at full-power level; continuing procurement of the initial orbiter flight spares and crew equipment; initiation of procurement of orbiter structural spares; installation of manufacturing tools for the external tank and solid rocket booster which will enhance their production rate capability; and continuing analyses of flight performance data from operational flights to improve understanding of the vehicle dynamics. In addition, work will continue on the development of a new structural case for the solid rocket motor made of composite materials and the necessary modifications to the orbiter and launch site

facilities for a new, high energy upper stage called Centaur.

The other principal areas of activity in Space Transportation Capability Development include NASA efforts related to the Spacelab, and upper stages to place satellites in higher altitude orbits; the engineering and technical base support at NASA centers; advanced programs study and evaluation efforts; and payload operations and support equipment.

The Spacelab, a joint effort with the European Space Agency (ESA), will be carried in the cargo bay of the Shuttle orbiter and will provide users with a multipurpose, reusable space laboratory. ESA is funding the development, production, and delivery of the first Spacelab and associated ground support equipment; NASA is providing for development of auxiliary flight and ground support equipment and procurement of additional sets of flight hardware and ground support equipment necessary to meet its mission requirements. Also included is funding to continue procurement of a second Spacelab from ESA. The first dedicated Spacelab flight is planned for launch in September 1983, with the second planned for September 1984.

Also continuing is the development, procurement, and integration of the Centaur upper stage in a joint development program with the Department of Defense. This stage will be used with the Shuttle for some planetary missions and for those Earth orbital missions requiring altitudes beyond the basic Shuttle capability and in excess of that provided by the other existing upper stages.

In advanced programs, two significant efforts will be pursued: initiation of development on a tethered satellite system, a new joint program with the Italian government, and continuation of studies related to a possible future Space Station. Other efforts will focus on technical and programmatic data for the definition and evaluation of potential future space missions and systems.

(b) *Space transportation system operations.*—This activity provides for the operation of the Space Shuttle and the expendable launch vehicles.

In 1984, STS operations efforts will continue the procurement, assembly, and checkout of the solid rocket boosters and external tanks, as well as standardized flight plans, avionics software, flight control systems, and crew procedures. The preparations in the preflight and direct mission support elements at Kennedy Space Center, Lyndon B. Johnson Space Center, and Marshall Space Flight Center will continue.

In 1984, missions to be supported include the launch of payloads for the Department of Defense, domestic commercial and foreign communications customers, and NASA payloads. Among the major NASA payloads are the Large Format Camera, Materials Processing Experiments, the Long Duration Exposure Facility, the Earth Radiation Budget Satellite, the Spacelab-3 Mission, and the retrieval/repair of the Solar Maximum Mission Spacecraft.

In expendable launch vehicles, this effort provides engineering, reliability, and launch support for the Delta until the transition to Shuttle operations is completed.

2. *Space science and applications.*—This activity supports systematic study of the Earth and its space environment, the solar system, the galaxy and the universe; and the research and selected technology developments to encourage the practical application of space technologies to needs on Earth.

(a) *Physics and astronomy.*—Research is being conducted to investigate the Earth's environment, the Sun and the interplanetary medium, the galaxy and distant space, as well as the interrelationships among these areas and the processes that control them. Past results include discovery of the Earth's radiation belts and knowledge of phenomena such as pulsars, quasars, and black holes.

Highlights of 1982 include the successful flight of the first space science payload on the Space Shuttle, which gathered solar physics data, evaluated the ambient and induced Shuttle environment, and provided data on payload thermal control technology. In addition, the Cosmic Ray Isotope Experiment was launched on a Department of Defense satellite to carry out galactic cosmic ray research.

Development work is continuing on the Space Telescope, planned to be launched in 1985, which will allow research at the forefront of optical and ultraviolet astronomy for decades. Work is also continuing on the Gamma Ray Observatory (GRO) mission planned for launch in 1988. The GRO will provide the highest sensitivity study of the sky conducted in the gamma ray spectral region.

Development and integration efforts also continue for payloads to be flown on Spacelabs 1 and 2 flights planned for launch in 1983 and 1985, respectively. Development activities for follow-on Spacelab payloads are also underway. Several multiuser payloads to investigate phenomena in the various disciplines are now being defined for future Spacelab missions. Plans for 1984 include the Spacelab payloads for Physics and Astronomy, and the mission management requirements for all agency payloads. Work is also continuing on several Explorer projects to continue research thrusts started in prior years.

(b) *Planetary exploration.*—This activity increases scientific knowledge about the origin and evolution of our solar system and of life processes, and applies the results to a better understanding of the Earth.

Work is continuing on the Galileo mission to Jupiter; the spacecraft is composed of two segments—an orbiter and an atmospheric entry probe. The Galileo orbiter and probe will be launched in 1986 on a Centaur Upper Stage and will achieve Jupiter orbit capture in 1989 to carry out long-term studies of the giant planet, its satellites, and its magnetosphere. The probe will enter the upper atmosphere of Jupiter. Development work is also continuing on U.S. experiments to be flown on the International Solar Polar Mission being developed by the Europeans, to explore the heliosphere, the space around the Sun, and to obtain observations of the Sun (launch in 1986).

Design and development will be initiated on the Venus Radar Mapper (VRM) mission in 1984 which will utilize synthetic aperture radar to map the surface of

General and special funds—Continued

RESEARCH AND DEVELOPMENT—Continued

Venus. The mission is targeted for a 1988 launch on a Centaur class upper stage.

Studies will be continued during 1984 on future candidate missions. Analysis of data from past planetary missions will also continue, including data from the Voyager and Pioneer missions.

(c) *Life sciences.*—This program will continue to provide for the research and technology necessary to meet the goals of ensuring human health, safety, well-being, and effective performance in space flight; utilizing space environment to advance knowledge and applications in Earth medicine and biology; and understanding the origin and distribution of life in the universe.

(d) *Space applications.*—This program category conducts coordinated and logically phased research and development activities to relate space technology to Earth benefits. The 1984 program provides for continued progress in the areas of materials processing in space, remote sensing, and communications. The activities involve active and increasing participation and funding by current and future users of these capabilities, within the Government, industry, and the academic community. The highlight of 1982 was the successful launch of Landsat-4 which will advance technology in remote sensing of the Earth from space.

The Materials Processing in Space program will continue to support fundamental research using the unique environment of space to enhance our basic knowledge of materials processing and to determine if space techniques can be used to control the composition and shape of materials. The research program includes high temperature heat pipes, electrostatic positioning methods, laser holography, acoustic positioning systems, and furnaces for directional solidification with high temperature gradients.

In communications, the 1984 program includes continued development and operation of the search and rescue experiment, further definition of an applications data service, and continuation of advanced communications research activities, including initiation of the Advanced Communications Technology Satellite (ACTS) design and development efforts. This mission will be a joint Government/industry undertaking wherein industry will provide a significant contribution toward the cost of the mission. ACTS is targeted for launch by the Space Shuttle in 1988.

In remote sensing, utilization of data from satellite observations has resulted in an increase in our understanding of the Earth's resources and environment, and in our ability to forecast change. Recent achievements include the successful launch of Landsat-4, a new-generation satellite with a Thematic Mapper which is providing imagery with improved spectral and spatial resolution; development and testing of techniques to predict severe storms; and use of SEASAT satellite experiments to measure ocean surface winds, sea state, major ocean currents, ocean circulation patterns, and sea ice conditions.

A wide range of similar activities will be continued during 1983 and 1984. Mobile laser units are being deployed in the United States, Australia, and the Pacific to form a global network for observation of tectonic plate motion. Ongoing efforts in the remote sensing area include analysis of data from the Landsat-4 Thematic Mapper and development of ground system capability; the Earth radiation budget experiment to acquire valuable data for climate studies, and the development of upper atmospheric research instruments. This group of instruments will provide the capability to obtain a global data set for studying the interaction between chemistry, radiation, and dynamics of the upper atmosphere.

3. *Technology utilization.*—This program is designed to facilitate the transfer of NASA technology to the nonaerospace industry, as well as State and local governments. During 1984, NASA will continue its efforts to help foster widespread dissemination of new technology developed by the Agency's programs.

4. *Space research and technology.*—The objective is to conduct the activities necessary to increase the efficiency and effectiveness of space systems and operations. The 1984 program provides for continuation of the research and technology base activities necessary for advances in the key discipline areas, and also continued progress in ongoing systems technology and experimental efforts.

5. *Aeronautical research and technology.*—The goal is to help preserve and strengthen long-term U.S. strength in aeronautical research and technology. Consistent with this goal, work will continue in 1984 on fundamental research in all basic aeronautical disciplines and the maintenance of related research facilities.

Activities will continue to provide a strong research and technology base in the aeronautical disciplines of aerodynamics, propulsion, avionics, and flight controls, human-vehicle interaction, materials, and structures; and to conduct generic technology activities relevant to the major classes of aeronautical vehicles such as subsonic aircraft, rotorcraft, and high performance aircraft.

In 1984, an important new effort will be the initiation of development of a numerical aerodynamic simulation capability in computational fluid dynamics which will provide new, powerful analytical techniques for the design of all types of future aerodynamic vehicles. Other new development efforts include an advanced composite structures technology and technology for next generation rotorcraft. In addition, ongoing major systems technology programs will be continued in rotorcraft and high-speed aircraft.

6. *Energy technology.*—In 1984, this program provides reimbursable support to Government agencies engaged in national energy programs.

7. *Supporting activities.*—This program provides tracking and data acquisition support to the entire NASA flight program, including automated missions, manned missions, sounding rockets, and aerodynamic test flights. Lease payments for the new Tracking and Data Relay Satellite System will continue in 1984.

Object Classification (in thousands of dollars)

Identification code 80-0108-0-1-999	1982 actual	1983 est.	1984 est.
Direct obligations:			
22.0 Transportation of things	12,947	16,187	15,915

23.1	Standard level user charges	347	364	567
23.2	Communications, utilities, and other rent	69,121	86,420	84,967
24.0	Printing and reproduction	6,856	8,572	8,428
25.0	Other services	4,316,377	5,396,695	5,305,946
26.0	Supplies and materials	163,235	204,090	200,658
31.0	Equipment	100,077	125,125	123,421
32.0	Lands and structures	1,616	2,020	1,986
41.0	Grants, subsidies, and contributions	845	1,057	1,039
42.0	Insurance claims and indemnities	60	75	73
99.0	Subtotal, direct obligations	4,671,481	5,840,605	5,743,000
	Reimbursable obligations:			
22.0	Transportation of things	751	1,121	1,200
23.2	Communications, utilities, and other rent	5,270	7,575	8,325
24.0	Printing and reproduction	44	67	77
25.0	Other services	782,730	1,124,939	917,105
26.0	Supplies and materials	9,942	14,290	15,000
31.0	Equipment	10,217	14,685	17,380
32.0	Lands and structures	361	518	633
99.0	Subtotal, reimbursable obligations	809,315	1,163,193	959,720
99.9	Total obligations	5,480,796	7,003,798	6,702,720

Construction of Facilities

For construction, repair, rehabilitation and modification of facilities, minor construction of new facilities and additions to existing facilities, and for facility planning and design not otherwise provided, for the National Aeronautics and Space Administration, and for the acquisition or condemnation of real property, as authorized by law, [$97,500,000] *$150,500,000*, to remain available until September 30, [1985] *1986*: *Provided*, That, notwithstanding the limitation on the availability of funds appropriated under this head by this appropriation Act, when any activity has been initiated by the incurrence of obligations therefor, the amount available for such activity shall remain available until expended, except that this provision shall not apply to the amounts appropriated pursuant to the authorization for repair, rehabilitation and modification of facilities, minor construction of new facilities and additions to existing facilities, and facility planning and design (*42 U.S.C. 2451, et seq.; Department of Housing and Urban Development—Independent Agencies Appropriation Act, 1983; additional authorizing legislation to be proposed.*)

Program and Financing (in thousands of dollars)

Identification code 80-0107-0-1-999

		Budget plan (amounts for construction of facilities actions programed)			Obligations		
		1982 actual	1983 est.	1984 est.	1982 actual	1983 est.	1984 est.
	Program by activities:						
	Direct program:						
	1. Space transportation systems	20,050	21,405	41,300	17,460	43,600	39,200
	2. Scientific investigations in space		1,740	12,000	1,085	3,200	10,000
	5. Aeronautical research and technology	22,650	20,115	24,000	20,109	43,500	32,400
	7. Supporting activity	56,000	54,240	73,200	53,577	69,900	74,700
	Total direct program	98,700	97,500	150,500	92,231	160,200	156,300
	Reimbursable program:						
	1. Space transportation systems	2,000	16,000	5,000	3,116	13,400	6,700
	5. Aeronautical research and technology	300	1,600	1,500	1,604	1,600	1,500
	7. Supporting activity		400	1,000	784	400	900
	Total reimbursable program	2,300	18,000	7,500	5,504	15,400	9,100
10.00	Total obligations	101,000	115,500	158,000	97,735	175,600	165,400
	Financing:						
11.00	Offsetting collections from: Federal funds	−2,300	−18,000	−7,500	−1,727	−18,000	−7,500
	Unobligated balance available, start of year: For completion of prior year budget plans:						
21.40	Direct				−112,616	−120,084	−72,384
21.40	Reimbursable				−6,900	−3,123	−5,723
22.40	Unobligated balance transferred from other accounts				−1,200	−15,000	
	Unobligated balance available, end of year: For completion of prior year budget plans:						
24.40	Direct				120,084	72,384	66,584
24.40	Reimbursable				3,123	5,723	4,123
25.00	Unobligated balance lapsing	33,426			33,627		
39.00	**Budget authority**	**132,126**	**97,500**	**150,500**	**132,126**	**97,500**	**150,500**
	Budget authority:						
40.00	Appropriation	95,800	97,500	150,500	95,800	97,500	150,500
42.00	Transferred from other accounts	2,900			2,900		
43.00	**Appropriation (adjusted)**	**98,700**	**97,500**	**150,500**	**98,700**	**97,500**	**150,500**
50.00	Reappropriation	33,426			33,426		
	Relation of obligations to outlays:						
71.00	Obligations incurred, net				96,007	157,600	157,900
72.40	Obligated balance, start of year				105,628	92,492	113,592
74.40	Obligated balance, end of year				−92,492	−113,592	−142,892
77.00	Adjustments in expired accounts				−137		
90.00	Outlays				109,006	136,500	128,600

General and special funds—Continued

CONSTRUCTION OF FACILITIES—Continued

This appropriation provides for the contractual services for the design, repair, major rehabilitation, and modification of facilities; the construction of new facilities; minor construction; the purchase of land and equipment related to construction and modification; and advanced design related to facilities planned for future authorization. The principal projects in the 1984 program are described below:

1. *Space transportation systems.*—This activity includes funds for Space Shuttle facilities at various locations.

2. *Scientific investigations in space.*—This activity includes the construction of a cargo hazardous service facility, and modifications to a spacecraft assembly and encapsulation facility for cargo processing at the John F. Kennedy Space Center, Fla.

5. *Aeronautical research and technology.*—This activity includes the construction of the fluid mechanics laboratory at the Ames Research Center, Moffett Field, Calif., and modifications and addition for the composite materials laboratory and modifications to the 30- by 60-foot wind tunnel at the Langley Research Center, Hampton, Va.; and modifications for small engine component testing facility and modifications to the icing research tunnel at the Lewis Research Center, Cleveland, Ohio.

7. *Supporting activity.*—The estimates for this activity include the construction of an aeronautical tracking facility at the Hugh L. Dryden Flight Research Facility, Edwards, Calif.; construction of a frequency standards laboratory and modifications to the space flight operations facility at the Jet Propulsion Laboratory, Pasadena, Calif.; and relocation of 26-meter STDN antenna, Spain; repair, rehabilitation and modification of facilities, not in excess of $500 thousand per project, and minor construction of new facilities and additions to existing facilities, not in excess of $250 thousand per project at various NASA installations and at Government-owned plants operated by contractors; and for facility planning and design.

Object Classification (in thousands of dollars)

Identification code 80-0107-0-1-999		1982 actual	1983 est.	1984 est.
	Direct obligations:			
31.0	Equipment	3,010	5,287	6,252
32.0	Lands and structures	89,221	154,913	150,048
99.0	Subtotal, direct obligations	92,231	160,200	156,300
	Reimbursable obligations:			
31.0	Equipment	8	62	36
32.0	Lands and structures	5,496	15,338	9,064
99.0	Subtotal, reimbursable obligations	5,504	15,400	9,100
99.9	Total obligations	97,735	175,600	165,400

RESEARCH AND PROGRAM MANAGEMENT

For necessary expenses of research in government laboratories, management of programs and other activities of the National Aeronautics and Space Administration, not otherwise provided for, including uniforms or allowances therefor, as authorized by law (5 U.S.C. 5901-5902); awards; [purchase (for replacement only, of two aircraft, for which partial payment may be made by exchange of at least one existing administrative aircraft and such other existing aircraft as may be considered appropriate),] *lease,* hire, maintenance and operation of administrative aircraft; purchase (not to exceed [seventeen] *twenty-seven* for replacement only) and hire of passenger motor vehicles; and maintenance and repair of real and personal property, and not in excess of $75,000 per project for construction of new facilities and additions to existing facilities, repairs, and rehabilitation and modification of facilities; [$1,168,900,000] *$1,247,500,000: Provided,* That contracts may be entered into under this appropriation for maintenance and operation of facilities, and for other services, to be provided during the next fiscal year: *Provided further,* That not to exceed [$25,000] *$35,000* of the foregoing amount shall be available for scientific consultations or extraordinary expense, to be expended upon the approval or authority of the Administrator and his determination shall be final and conclusive. *(42 U.S.C. 2451, et seq.; Department of Housing and Urban Development—Independent Agencies Appropriation Act, 1983; additional authorizing legislation to be proposed.)*

Program and Financing (in thousands of dollars)

Identification code 80-0103-0-1-999		Budget plan			Obligations		
		1982 actual	1983 est.	1984 est.	1982 actual	1983 est.	1984 est.
	Program by activities:						
	Direct program:						
1	Space transportation systems	476,374	489,850	509,700	476,298	489,929	509,700
2	Scientific investigations in space	175,928	189,600	202,300	170,050	189,600	202,300
3	Space and terrestrial applications	105,725	112,500	115,000	111,499	112,500	115,000
4	Space research and technology	84,089	95,100	98,700	84,068	95,100	98,700
5	Aeronautical research and technology	228,872	252,700	265,100	228,806	252,700	265,100
6	Energy technology	10,843	2,800		10,840	2,800	
7	Supporting activity	52,519	56,500	56,700	52,494	56,500	56,700
	Subtotal direct program	1,134,350	1,199,050	1,247,500	1,134,055	1,199,129	1,247,500
	Program funded for R&D	48,950			48,950		
	Program funded in this account	1,183,300	1,199,050	1,247,500	1,183,005	1,199,129	1,247,500
	Reimbursable program:						
1	Space transportation systems	22,564	24,600	24,600	22,564	24,600	24,600
2	Scientific investigations in space	115	130	130	115	130	130
3	Space and terrestrial applications	6,184	6,800	6,800	6,184	6,800	6,800
4	Space research and technology	14	20	20	14	20	20
5	Aeronautical research and technology	403	450	450	403	450	450

	6 Energy technology	16,518	18,000	18,000	16,518	18,000	18,000
	Total reimbursable program	45,798	50,000	50,000	45,798	50,000	50,000
10 00	Total obligations	1,229,098	1,249,050	1,297,500	1,228,803	1,249,129	1,297,500
	Financing:						
	Offsetting collections from:						
11 00	Federal funds				−25,215	−27,500	−27,500
14 00	Non-Federal sources				−20,583	−22,500	−22,500
21 40	Unobligated balance, start of year					−79	
24 40	Unobligated balance, end of year				79		
25 00	Unobligated balance lapsing				216		
39 00	**Budget authority**				**1,183,300**	**1,199,050**	**1,247,500**
	Budget authority:						
40 00	**Appropriation**				**1,183,300**	**1,168,900**	**1,247,500**
44 20	**Supplemental for civilian pay raises**					**30,150**	
	Relation of obligations to outlays:						
71 00	Obligations incurred, net				1,183,005	1,199,129	1,247,500
72 40	Obligated balance, start of year				83,081	133,266	82,395
74 40	Obligated balance, end of year				−133,266	−82,395	−82,395
77 00	Adjustments in expired accounts				−2,801		
90 00	Outlays, excluding pay raise supplemental				1,130,019	1,219,850	1,247,500
91 20	Outlays from civilian pay raise supplemental					30,150	

This appropriation provides for research in Government laboratories, management of programs, and other expenses for the operation of NASA installations.

Responsibility for the space transportation systems activity is located at the John F. Kennedy Space Center, Kennedy Space Center, Fla.; Lyndon B. Johnson Space Center, Houston, Tex.; Marshall Space Flight Center, Huntsville, Ala.; and the National Space Technology Laboratories, Bay St. Louis, Miss. The scientific investigations in space and space and terrestrial applications activities are concentrated principally at the Ames Research Center, Moffett Field, Calif.; Goddard Space Flight Center, Greenbelt, Md.; Langley Research Center, Hampton, Va.; Lewis Research Center, Cleveland, Ohio; Lyndon B. Johnson Space Center; Marshall Space Flight Center; and the National Space Technology Laboratories.

The space research and technology activity is conducted at the Ames, Goddard, Langley, Lewis, Johnson, and Marshall Centers.

Aeronautical research and technology work is conducted at the Ames, Langley, and Lewis Research Centers.

Programwide support and management are provided by NASA headquarters, Washington, D.C. Support activities for tracking and data acquisition requirements are performed at the Goddard Space Flight Center.

Object Classification (in thousands of dollars)

Identification code 80-0103-0-1-999		1982 actual	1983 est.	1984 est.
	Direct obligations:			
	Personnel compensation:			
11 1	Full-time permanent	718,981	746,586	749,077
11 3	Other than full-time permanent	16,006	16,775	17,008
11 5	Other personnel compensation	10,131	11,750	12,684
11 8	Special personal services payments	4,093	4,435	4,339
11 9	Total personnel compensation	749,211	779,546	783,108
12 1	Personnel benefits: Civilian	73,837	88,861	92,314
13 0	Benefits for former personnel	636	431	365
21 0	Travel and transportation of persons	19,753	23,800	25,700
21 0	Payments to interagency motor pools	1,163	1,375	1,717
22 0	Transportation of things	1,906	2,546	2,728
23 1	Standard level user charges	5,517	7,844	8,480
23 2	Communications, utilities, and other rent	84,746	100,914	114,374
24 0	Printing and reproduction	5,441	5,565	5,957
25 0	Other services	207,411	160,418	185,298
26 0	Supplies and materials	20,334	20,471	22,358
31 0	Equipment	12,328	7,240	4,978
32 0	Lands and structures	566		
41 0	Grants, subsidies, and contributions	141	102	107
42 0	Insurance claims and indemnities	15	16	16
99 0	Subtotal, direct obligations	1,183,005	1,199,129	1,247,500
	Reimbursable obligations:			
	Personnel compensation:			
11 1	Full-time permanent	17,055	11,915	12,214
11 3	Other than full-time permanent	31	9	
11 5	Other personnel compensation	90	25	18
11 9	Total personnel compensation	17,176	11,949	12,232
12 1	Personnel benefits: Civilian	1,714	1,389	1,706
21 0	Travel and transportation of persons	3,267	4,717	4,922
23 2	Communications, utilities, and other rent	8,298	8,574	9,457
24 0	Printing and reproduction	55	66	71
25 0	Other services	13,993	21,880	20,345
26 0	Supplies and materials	1,189	1,348	1,252
31 0	Equipment	106	77	15
99 0	Subtotal, reimbursable obligations	45,798	50,000	50,000
99 9	Total obligations	1,228,803	1,249,129	1,297,500

Personnel Summary

Total number of full-time permanent positions	21,652	21,279	21,219
Total compensable workyears:			
Full-time equivalent employment	23,001	22,517	22,517
Full-time equivalent of overtime and holiday hours	231	234	243
Average ES salary	$58,400	$63,800	$63,800
Average GS grade	11.21	11.24	11.24
Average GS salary	$34,297	$35,992	$36,189
Average salary, grades established by the Administrator, NASA	$55,800	$61,400	$61,400
Average salary of ungraded positions	$24,099	$26,069	$27,300

Trust Funds

MISCELLANEOUS TRUST FUNDS

Program and Financing (in thousands of dollars)

Identification code 80-9971-0-7-255		1982 actual	1983 est.	1984 est.
	Program by activities:			
	1. International cooperation	2	17	
	2. Gifts and donations		145	
10.00	Total obligations (object class 25.0)	2	162	
	Financing:			
17.00	Recovery of prior year obligations	−57		
21.40	Unobligated balance available, start of year	−39	−162	
24.40	Unobligated balance available, end of year	162		
60.00	**Budget authority (appropriation)** (permanent, indefinite)	68		
	Relation of obligations to outlays:			
71.00	Obligations incurred, net	2	162	
72.40	Obligated balance, start of year	1	3	
74.40	Obligated balance, end of year	−3		
78.00	Adjustments in unexpired accounts	−57		
90.00	Outlays	−57	165	

International cooperation.—U.S. dollars are advanced from foreign governments to allow the National Aeronautics and Space Administration to procure, in the United States, nonmilitary space-oriented materials and services on their behalf. Authority for this action is granted by the National Aeronautics and Space Act of 1958 (42 U.S.C. 2451 et seq.).

EDITORIAL RESEARCH REPORTS

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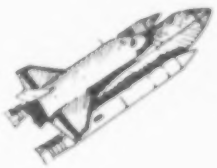
Feb. 18
1983

AMERICAN OPTIONS IN SPACE



by

Katrina Farrell-Gisse
and Hoyt Gimlin

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AMERICAN OPTIONS IN SPACE

IT HAS been a quarter-century since America put its first satellite into space and a decade since the last lunar expedition closed the era of flag-bearing astronauts *(see Space Events, p. 134)*. These exploits captured the public's imagination and ensured financial support for the U.S. space program through the 1960s. During the following decade, the National Aeronautics and Space Administration (NASA) scored remarkable successes with its unmanned probes of other planets, and it mapped plans for space travel in the 1980s as difficult and perhaps as exciting as the Man-on-the-Moon program that President Kennedy set in motion in 1961.

Motivated by the high cost of space travel, NASA searched for more efficient ways to exploit space and its resources. This fostered the idea of a Space Transportation System, or STS, for carrying cargoes ("payloads") into orbit and returning to Earth aboard a fleet of reusable space shuttles *(see illustrations, p. 133)*. Now after five successful flights of the space shuttle *Columbia*, the first flight of the new shuttle *Challenger* from the Kennedy Space Flight Center in Florida is scheduled for sometime in middle or late March — barring further delay that postponed the original launch date from Jan. 27 because of a fuel tank flaw. Though a setback, which is likely to postpone the launching of other flights this year, it does not dampen optimism in the space agency that the United States is on the verge of a commercial, scientific and military renaissance in space.

However, this view is not universally shared. The science community is complaining that space sciences are taking a back seat to the military applications of space. And as for America's attempt to push ahead with the commercialization of space, it is encountering competition from Russia, Europe and Japan. In recent years, all three have been developing inexpensive means of launching satellites, and at least Europe and Japan are trying to attract some of the international business — including American business — that NASA was counting on to support the commercial aspect of the Space Transportation System.

There is an ambitious schedule of shuttle flights, nevertheless. Sixty-three are planned through 1987. This September the

Columbia is due to carry aloft a $1 billion Spacelab developed by the European Space Agency[1] for NASA, enabling scientists to work in a "shirt-sleeve environment" — without bulky spacesuits and carry out experiments for research institutes, commercial customers and government agencies.

Then in March 1984, if the timetable holds firm, the new shuttle *Discovery* will make its first flight. It will carry a communications satellite and a facility for experimenting with the separation of chemical compounds that can best be performed where gravity is weak or virtually absent. This kind of "materials processing" will be studied further in April 1985 when the shuttle *Atlantis* is sent into orbit. This will be done in a Spacelab mission jointly sponsored by NASA and the West German goverment.

About one-third of the *Atlantis* payload capacity will be leased to private, commerical interests — unless opposition that has been reported in the White House materializes to block the plan. The trade magazine *Aviation Week & Space Technology* has reported that David A. Stockman, director of the presidential Office of Management and Budget, does not want federally funded space transportation to haul private cargoes unless the government realizes a profit from that activity.[2]

Selling Industry the Shuttle's Services

NASA is moving ahead despite any official misgivings, promoting its "Getaway Special." For fees up to $10,000, individuals and corporations can lease up to five cubic feet of space aboard a future shuttle flight, and place up to 200 pounds on board. So far about 500 customers have signed up to have their cargoes, usually involving scientific experiments, taken into orbit. The agency is also developing plans to take passengers into space late in this decade.

Business involvement in the U.S. space program is not new, of course. Since its inception, NASA has contracted with large companies for a variety of services and products. Private industry has supplied parts and developed entire systems for space projects. The prime contractor for the space shuttle orbiter, for instance, is Rockwell International's Space Division at Downey, Calif. Hundreds of other private companies are subcontractors. Now that the space shuttle is operational, the private sector of the economy is looking at it with wider interest.

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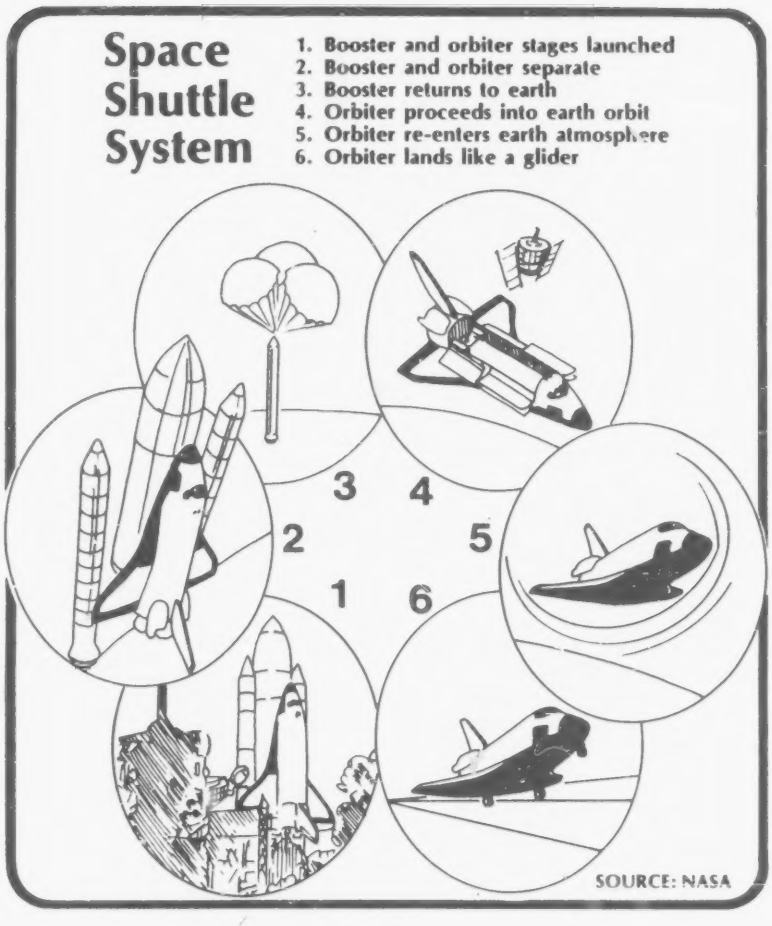
[1] The agency is an adjunct of the European Economic Community composed of Belgium, Britain, Denmark, France, West Germany, Greece, Ireland, Italy, Luxembourg and the Netherlands.

[2] *Aviation Week & Space Technology*, Oct. 25, 1982, p. 11.



Communications satellites were the shuttle's first commercial payload. Last November the *Columbia* carried into space and launched two $30 million satellites for Telsat Systems of Canada and Satellite Business Systems of McLean, Va. Each paid NASA $9 million for performing this service, enabling Telsat to beam television signals to rooftop antennas in Canada and SBS to operate a long-distance telephone system.

More than three years before that event, a NASA planner, Jesco von Puttakamer, predicted that communication satellites would constitute the shuttle's main payloads throughout the 1980s. "[U]sing the shuttle," he explained, it will be practical "to assemble much larger antennas and reflector structures than those we now have in orbit." [3] Even then, in 1979, commercial investments in satellites had exceeded $1 billion, von Putta-

[3] Jesco von Puttakamer, "The Industrialization of Space: Transcending the Limits of Growth," *The Futurist* (magazine of the World Future Society), June 1979, p. 184.

Space Events, 1957-82

1957.	Russia launches first satellite Sputnik on Oct. 4.
1958.	U.S. sends up its first satellite, Explorer, Jan. 31.
1960.	Echo 1, first TV communications satellite in orbit.
1961.	Cosmonaut Yuri A. Gagarin becomes first human in orbit, April 12. President Kennedy calls May 26 for moon landing.
1962.	John Glenn becomes first American to orbit the Earth, Feb. 20. First successful interplanetary mission, Mariner 2 to Venus.
1963.	Soviets put first woman, Valentina Tereshkova, in space.
1965.	U.S. launches first 2-man mission, March 23. First space walk by cosmonaut Alexey Leonov. Early Bird, first commercial communications satellite, links U.S. and Europe.
1966.	Venera 3 lands on Venus, first man-made object to reach another planet.
1969.	U.S. lands first men on moon, July 16.
1971.	Russia's Salyut 1 becomes first space station in Earth's orbit.
1972.	President Nixon authorizes space shuttle, Jan. 5. Last Apollo mission, Dec. 7-19.
1973.	First Skylab crew launched May 26.
1974.	Skylab 4 crew aloft 84 days, a record. Mariner 10 conducts first probe of Mercury.
1975.	Apollo-Soyez projects links U.S.-Soviet crews in space, in July.
1981.	Space shuttle makes first of test flight, April 12.
1982.	Shuttle's first operational mission, Nov. 11.

kamer reported, predicting that the figure would be several times greater by the mid-1980s.

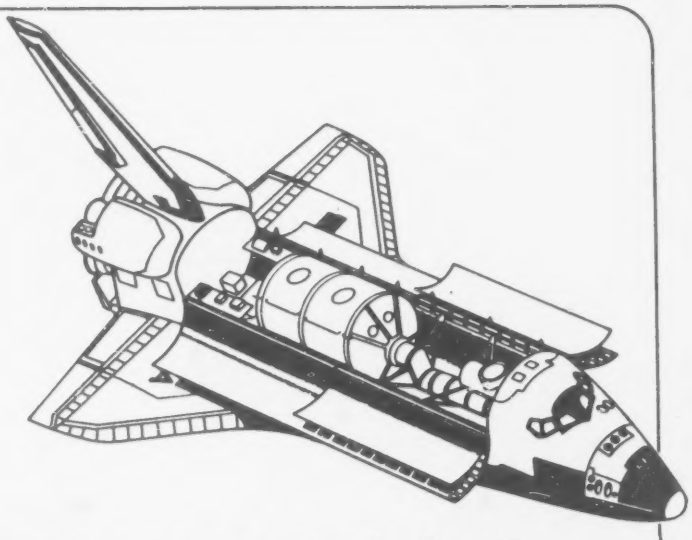
Communication satellites receive signals from a ground station and retransmit them over a very broad area, eliminating the need for telephone and telegraph lines, cables and other surface means of communication. American Telephone & Telegraph Co. put up the first working communication satellite, Telstar, on July 20, 1962, to transmit telephone calls and some television signals across the Atlantic Ocean. Though disabled the next year, Telestar was followed by a procession of others.

Commercial interest in satellites was so strong that in 1962 Congress authorized the creation of the Communication Satellite Corp. (Comsat), jointly controlled by private industry and the federal government.[4] Comsat arranged with NASA to launch scores of satellites for communications purposes. There also have been dozens of satellites for weather observations, navigation, traffic control, mapping and surveying.

Spawning the Communications Economy

Social forecaster John Naisitt makes the point that today's shuttle can orbit a 65,000-pound payload vastly greater than the

[4] See Congressional Quarterly's *Congress and the Nation*, Vol. I (1965), pp. 320, 326.



NASA's concept of shuttle carrying Spacelab into orbit

182-pound Sputnik, "and many, many times more sophisticated." In the past, the complex parts of a satellite system had to be in a ground station. "But the new shuttle . . . can launch larger satellites that incorporate ground station functions. . . ."

For all that "the space shuttle has a lot more to do with the globalized information economy than it will ever have to do — in our lifetimes — with space exploration." he added. "I do not want to minimize the importance of *Sputnik* and *Columbia* in opening up the heavens to us. But what has not been stressed enough is the way satellites transformed the Earth into what Marshall McLuhan called a global village."[8]

"No one looking at space a quarter century ago foresaw all ways in which space systems have altered human life," writes Daniel Deudney, a senior researcher with Worldwatch Institute, "and no one today predicting space activities over the next 50 to 100 years is likely to predict all the uses to which satellites will be put. Yet enough is known about the potential of space and the needs of earth that some ideas — large-scale space colonies, solar power satellites and asteroid mining — can be eliminated as practical and desirable goals. A modest industry producing

[8] John Naisbitt, *Megatrends*, Warner Books, 1982, pp. 12, 58. Naisbitt is publisher of the quarterly *Trend Report* and chairman of the Naisbitt Group, a research and consulting firm, in Washington, D.C. McLuhan, a Canadian professor-author, has been called the guru of the age of television. He is perhaps best known for his book *The Medium is the Massage* — or message.

certain high quality products is possible within this time horizon, but is unlikely to surpass the economic contribution of communications satellites."[6]

> The success of the satellite communications industry [Deudney added] has spawned a great deal of speculation about the possibility of building industries in space. Experiments aboard the U.S. *Skylab* in 1974 revealed that the weightless, airless conditions of space enabled the production of certain goods that are impossible to manufacture on Earth. Without gravity, crystals form much more regularly, permitting the creation of glasses and electrical devices that have vastly higher performance than any others. And the products can be formed without containers, eliminating impurities that are the major limit to the performance of certain optical and metallurgical products on Earth.[7]

The drug industry is expected to become one of the main users of weightless space. A Johnson & Johnson subsidiary is working with NASA to conduct an extensive research program. Jesco von Puttakamer, the NASA planner, estimates that space manufacturing could lower the production cost of a drug to prevent blood clots from $1,200 a dose to about $100.

Electrophoresus Operations in Space (EOS), a subsidiary of the McDonnell Douglas aerospace manufacturing company, is reported to be experimenting extensively with producing pharmaceuticals and other materials in space. An official of the company said it was investing "millions of dollars" in materials research to determine what products could benefit from production in space. The results so far show that "hundreds" of new or improved products could be produced there.

NASA has predicted that it will not have enough launch facilities to meet the demand once big businesses become actively engaged in space manufacturing. Some companies are reported to be considering ways of establishing their own space transportation systems and bypassing the shuttle. One company, Space Services Inc. of Houston, went a step further last September by launching a small spacecraft made of surplus parts and carrying a mock payload of 40 gallons of water. It soared to 52.9 miles and plunged into the Gulf of Mexico, 326 miles from the Matagorda Island launch site in Texas. The test was part of the company's plan eventually to sell "low-cost, market-oriented" space services to customers, according to David H. Hannah Jr., the company chairman.[8]

The main problem facing a company that wants to go into

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[6] Daniel Deudney, "Space: The High Frontier — Worldwatch Paper 50," August 198 , p. 39. It was published by the Worldwatch Institute, 1776 Massachusetts Ave., N.W., Washington, D.C. 20036.

[7] *Ibid*, p. 39. Also see Henry Cooper's 2-part articles "Shuttle I" and "Shuttle II" in *The New Yorker*, Feb. 9 and 16, 1981.

[8] Quoted in *The New York Times*, Sept. 10, 1982

space transportation is finding a competitive alternative to NASA's shuttle. It conceivably could purchase boosters that the space agency no longer uses. Possibly a well-financed company could build its own shuttle, or buy one of NASA's — as the Space Transportation Co. of Princeton, N.J., has been attempting to do for an offering price reported to be about $1 billion.

Fairchiid Industries at Germantown, Md., is spending more than $100 million to study the feasibility of building a series of "spacecraft buses," a company official said. Each "bus" would be launched into low orbit by NASA's space shuttle and then use onboard propulsion to move into higher orbit. Fairchild envisions leasing all or some of its "buses" to other companies.

While large companies such as Fairchild and McDonnell Douglas may need no further encouragement to invest in space research, many smaller ones remain skeptical that such ventures will be profitable. NASA's Customer Services office is developing pricing policies to persuade them to become shuttle users. However, the U.S. General Accounting Office has recommended to Congress that NASA charge more for use of the shuttle and gradually abandon its low-pricing policy.[9] NASA is technically a research and development agency and thus is not supposed to market its activities. This fact has led the agency to consider handing its shuttle operations over to a private company. NASA Administrator James M. Beggs is expected to make a decision this year on such a transfer.

Rising Competition in Europe and Japan

As the United States tries to find the right combination of government and industry involvement in the commercialization of space, several foreign countries are swiftly becoming competitive. The congressional Office of Technology Assessment recently advised the lawmakers that "increased foreign competition and stringent fiscal restraints" in the United States could diminish the U.S. lead in satellite communications, land-remote sensing, transportation and materials processing in space.[10]

Phil Culbertson, NASA associate deputy administrator, has said that the Japanese "have made major inroads in communications technology, and the Europeans are now vigorously marketing a launch system." [11] The European Space Agency's three-stage launch rocket, *Ariane*, already has lured commercial users away from the U.S. shuttle.[12] *Ariane's* American customers include Western Union, which has booked

[9] General Accounting Office, "NASA Must Reconsider Operations Pricing Policy for Cost Growth on the Space Transportation System," report to Congress by the Comptroller General, Feb. 23, 1982.

[10] "Civilian Space Policy and Applications," OTA report to Congress, June 15, 1982; Government Printing Office, Washington, D.C. 20402.

[11] Quoted in *Congressional Quarterly Weekly Report*, June 24, 1982, p. 1764.

[12] See *Aviation Week & Space Technology*, Oct. 4, 1982, p. 22.

its Westar satellite for launching this year, and Southern Pacific Communications of California. But unlike the shuttle, the unmanned Ariane cannot retrieve satellites or carry astronauts aboard to repair and replace damaged satellites.

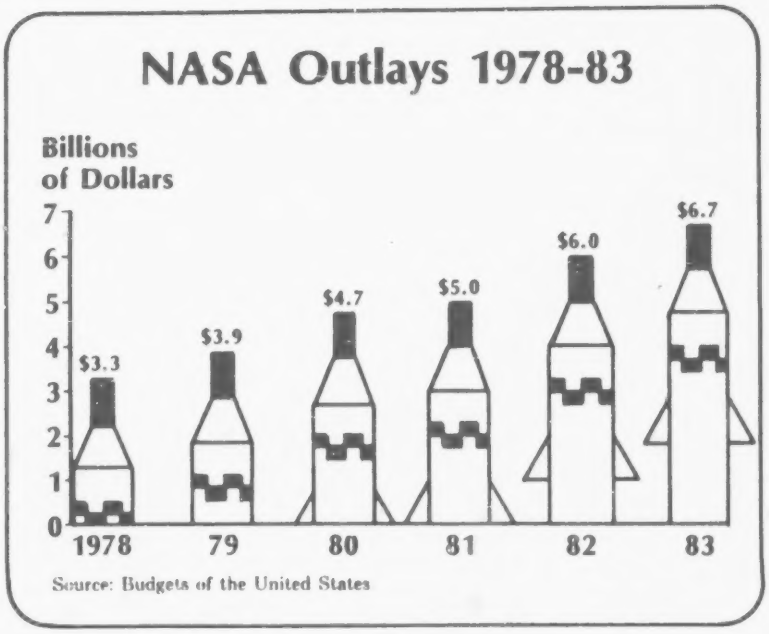
Militarization of Space

WHILE the United States was developing the space shuttle, the Soviet Union was creating and launching *Salyut* space stations. The first one, in 1971, and subsequent ones in 1972, 1973, 1975 and 1977 have been characterized by James E. Oberg, a Soviet affairs specialist at NASA, as of the "civilian" variety. But he said others that were launched in 1973, 1974 and 1976 were essentially for military purposes.[13] However, it is often difficult to separate military purposes from the scientific—since any number of scientific advances in space can be adapted to military uses.

It is no secret that both the United States and Russia eye each other's space efforts warily, and often accuse the other of being obsessed with the military applications of space technology. According to the Department of Defense, the Soviet Union spends about 70 percent of its space budget on military-oriented missions, and an additional 15 percent on combined military and civilian activities.[14] About 20 percent of NASA's $6.6 billion budget in this fiscal year is allocated to military missions. However, there is an additional $8.3 billion in the Defense budget for military space activities, bringing America's military share of its total $14.9 billion space budget close to 70 percent also.

"Space in military terms is big, important business and getting more so," *Air Force Magazine* observed last summer.[15] Among the military services, the Air Force gets the lion's share of space money, some $7.2 billion in this fiscal year's budget, amounting to 9 percent of the Air Force's spending. The Air Force plans to use the space shuttle as a launching pad for spy satellites and for satellite service, repair and modification. Eventually it would like to use the shuttle as a base for assembling a manned space station which, among other things, could launch spacecraft to higher orbits for longer duration.

[13] See Oberg's book, *Red Star in Orbit* (1981).
[14] See "Soviet Military Power," publication released by the Public Correspondence Division, Office of Assistant Secretary of Defense for Public Affairs, 1982.
[15] *Air Force Magazine*, August 1982, p. 49. The magazine, published by the Air Force Association, does not officially speak for the Air Force but usually reflects its views.



Of the 234 shuttle flights scheduled through 1994, according to the General Accounting Office, 114 (48 percent) are military related; 13 of the initial 44 flights through 1986 are specifically military. NASA officials say that most of the shuttle's current military missions are "passive" — they involve such things as weather predictions, surveillance (spy satellites), navigation and communications. But the shuttle also is equipped to launch satellites that would give early warning of missile attacks, and would provide advanced and improved navigation for warships, warplanes and military vehicles.

Fear of Soviets Holding 'High Ground'

While "militarization of space" has been decried in Congress and in the press, Defense officials argue that the alternative is to let Russia gain uncontested control of "the high ground" and thus threaten U.S. security. They point to Soviet cosmonauts repeatedly setting records for length of time in orbit, currently up to 211 consecutive days, and note that Russia launches more satellites than the United States does. In June 1982, the Soviets established a new record by placing 15 satellites in orbit, about the same number this country launched in all of 1981. During that entire year, according to U.S. calculations, the Russians launched 858 military and 392 civilian satellites.

Some of the satellites conduct routine military tasks such as communications, mapping and reconnaissance. Like other nations with satellites in orbit, they are used to monitor world grain crops. Other satellites are more worrisome. U.S. sources

say the Soviets have flown and tested about 20 "killer" satellites, designed to track down and destroy enemy satellites, spaceships and space stations. The Russians reportedly are also testing "space mines" — killer satellites which would orbit the Earth for long periods of time, awaiting detonation by ground command, for purposes as yet unknown. A Department of Defense spokesman said at least one Soviet killer satellite circles the Earth in a low orbit.

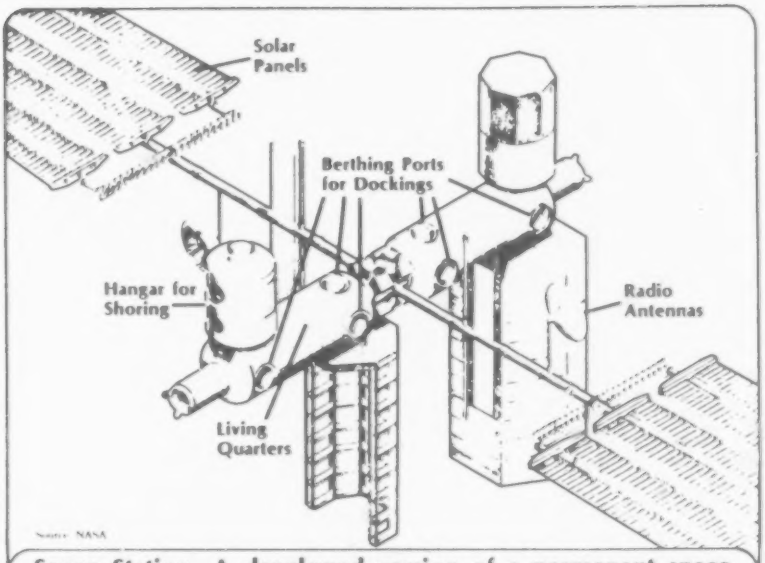
Like their American counterparts in the shuttle, Soviet cosmonauts use their Salyut space stations to conduct "civilian" experiments — the manufacture of special materials, seed growth in zero gravity, and an assortment of scientific activities. But it's the secret, military missions of the Soviet space program that worry U.S. officials. Richard D. DeLauer, Undersecretary of Defense for research and engineering, told a Senate Foreign Relations subcommittee last fall that the Salyut program "engages in military activities and may be the forerunner of a weapons platform."[18]

There is disagreement among experts whether Russia is ahead or behind the United States in its space activity. The Soviet program presumably does not have a reusable craft such as the U.S. shuttle — but that is not certain. There is some belief that, although unadvertised, a reusable Soviet space vehicle is being developed. As for Russia having more satellite launchings, that may reveal weakness rather than strength. The Soviet satellites usually do not remain operational as long as American satellites, so more of them must be put into orbit.

Nevertheless, Soviet space operations have been impressive to many. Oberg, for instance, believes Russia is developing the Salyut as a small basic space station in order to acquire long-term experience in space operations. Already, Soviet cosmonauts have spent more than twice as much time in orbit than have American astronauts. Valeriy Ryumin, the most experienced civilian engineer-cosmonaut, accumulated 362 days of space flight on three missions in 1977, 1979 and 1980.

While U.S. experts predict the Russians will continue to use expendable boosters and capsules in the near future, it is likely that at the same time they are developing a permanent space station to be manned by three or four cosmonauts for as long as a year at a time. It is envisioned that later in the 1980s or in the 1990s, Soviet space stations would be able to accommodate up to six crewmen. Boris Petrov, chairman of the Soviet Interkosmos Council, has been quoted as saying "scientists are already busy designing large stations for a crew of 12 to 20, with

[18] Testimony before the Subcommittee on Arms Control, Oceans, International Operations and Environment, Sept. 20, 1982.



Space Station. A developed version of a permanent space station. Included is a scientific space laboratory, a materials-processing factory, a module for servicing payloads and another for fabrication of large space systems.

a life span of up to 10 years, which would replace the present small stations."[17] Soviet scientists also have predicted the appearance of "space towns" by the end of the century.

Permanent Bases Aloft; Killer Satellites

American space buffs, too, are enthusiastic about the idea of a space station. NASA Administrator Beggs has called a manned space station "the next logical step" after the development of the shuttle. He envisions it as the assembly point for manned and unmanned missions to Mars and other planets.[18] The space agency has contracted with eight aerospace companies[19] to study the potential commercial, military and scientific uses of a space station. The study results are expected in April.

Although President Reagan issued a national space policy statement last July 4, he stopped short of backing a big new project, such as a manned space station. His statement instead included a general endorsement of the space program and a commitment to the use of space for commercial and national security purposes. Reagan set out a number of civilian objec-

[17] James Oberg, *op. cit.*, p. 232.
[18] His views were outlined in a speech to the Detroit Economic Club and the Detroit Engineering Society, June 23, 1982.
[19] Boeing Aerospace Co., Seattle; General Dynamics Corp., Convair Division, San Diego; Grumman Aerospace Corp., Bethpage, N.Y.; Lockheed Missile and Space Co., Sunnyvale, Calif.; Martin Marietta Aerospace, Denver Aerospace, Denver; McDonnell Douglas Astronautics Co., Huntington Beach, Calif.; Rockwell International, Space Operations/Integration and Satellite Systems Division, Downey, Calif.; and TRW Inc., Defense and Space Systems Groups, Redondo Beach, Calif.

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International Law and Outer Space

The main international agreement governing outer space was drafted in 1967 by a U.N. body and is known today as the Outer Space Treaty. It has been signed by 107 countries, including all that are active in space.

A second U.N.-sponsored space agreement, known as the Moon Treaty, was drafted in 1979 but has been ratified by only three countries, of which only one (France) has a space program. The 1967 treaty holds that outer space is not subject to national appropriation while the later one goes a step further, saying that the moon and other celestial bodies are the "common heritage of mankind" — a concept promoted by Third World countries but resisted by both the industrial West and Russia.

tives, including research and experimentation in the origin and evolution of the universe and solar system, the Earth's environment and its relation to the sun, and the technology of permanent space facilities. He also called for "a climate conductive to expanded private sector investment and involvement in space activities."

For national security aspects of space, the policy stated that the United States will proceed with development of an anti-satellite capability to deter threats to U.S. space systems. The statement added that the United States would develop an attack warning, notification and verification capability to detect and react to threats to the United States in space. A Fact Sheet issued by the White House describing the policy noted that it grew out of a National Security Council study, which explains its emphasis on defense issues, analysts said.

Scarcely more than a month after Reagan issued his policy statement emphasizing military aspects of space, the secretary general of the United Nations, Javier Perez de Cuellar, opened a U.N.-sponsored conference in Vienna on the future of outer space by warning that an arms race in space holds the "potential for confrontation."[20]

Russia and the United States negotiated off and on during the 1970s to control anti-satellite weapons, but the talks broke off at the end of the decade when Russia invaded Afghanistan. One immense barrier to agreement was Russia's insistence that the space shuttle be considered an anti-satellite system since it had the capability of intercepting and destroying Soviet satellites. The United States argued that shuttles are too expensive ever to become numerous[21] and, moreover, are not feasible anti-satellite weapons.

[20] Statement to the Unispace '82 Conference, Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Aug. 9, 1982.

[21] Costs run to about $1 billion apiece; the United States currently expects to build only four.

American Options in Space

Both the United States and Russia are known to be trying to build an even more futuristic weapon using laser beams. As envisioned, powerful lasers in orbit would intercept and destroy intercontinental ballistics missiles in flight as they arc above the Earth. However, it has been estimated that a laser ray system capable of providing the United States protection from Soviet ICBMs might cost $1 trillion or more. There is an even greater drawback. "Using space-based lasers as a ballistic missile defense suffers from the same problems — in spades — that led the U.S. and U.S.S.R. to agree by treaty to abandon all anti-ballistic missiles a decade ago," Daniel Deudney writes. "The central problem of all anti-ballistic missile systems is the ease with which the highly sensitive radars that track oncoming missiles can be utterly blinded."[33]

The American public appears about evenly divided on whether the U.S. space program should focus primarily on national defense or scientific exploration. In an NBC/Associated Press poll conducted in 1981, 47 percent of the people questioned favored a military emphasis while 43 percent said scientific aspects should be emphasized. The remaining 10 percent wanted an equal emphasis on both.

Directions of Space Science

MILITARY and commercial endeavors in space are possible only because gigantic strides have been made in space science and technology during the past quarter-century. Space science can be divided into two types: that which looks inward for a better understanding of our own planet and that which looks outward for a better understanding of the universe. A comparison of the NASA Space Science Program budgets in 1965 and 1983 indicates that today outer space is taking a back seat to the shuttle and Earth satellite programs. The 1983 figure is $697.8 million, less than half of the 1965 outlay in terms of constant dollars — without the effects of inflation. NASA's planetary missions make up only about 5 percent of the space agency's current budget.

The commitment to the shuttle and Earth satellites has led to the cancellation of postponement of several scientific projects. NASA's Office of Space Science has only two major missions in this decade, putting the Space Telescope *(see p. 146)* in orbit and sending another spacecraft to Jupiter. In contrast, there were 24 missions in the 1970s. NASA also postponed to 1987-88

[33] Daniel Deudney, *op. cit.*, p. 25.

Nuclear-Powered Satellites

Since a nuclear reactor can generate much more power for a satellite than the usual array of solar panels, they are favored for "supersatellites" of the future — especially for military purposes. Already the United States has one aloft and Russia has launched 18. One was Cosmos 1402, which plunged into the Indian Ocean Jan. 23 — except for fiery fragments of final piece which came down in the South Atlantic Feb. 7. They landed far from human habitation but caused concern over a cloud of radioactive dust the satellite's reaction left in the upper atmosphere.

Another nuclear-powered Cosmos crashed into a remote area of northern Canada in 1978. In that case the reactor's uranium fuel burned up high in the atmosphere and apparently spared the impact area of radioactive contamination. American space officials say that Russia has put up 18 nuclear-powered satellites during the past several years. The United States launched one such satellite in 1965 which is still operating in orbit. Defense officials are reported to be considering adding others.

a Gamma Ray Observatory to help astronomers study the universe at very high frequencies. The project Venus Orbiting Imaging Radar, which would study the cloud-covered Venusian surface in detail, also has been delayed.

Carl Sagan, the astronomer-author, has said that future knowledge of "deep" space is being denied by present-day cancellations and postponements. "We are the beneficiaries of decisions made in the 1960s and the 1970s," he said. "There are no new starts in this decade, with the single exception of Galileo . . . and that worries me greatly."[33]

American scientists are especially upset that NASA has decided not to sponsor a space probe to enter and investigate the great swath of ice, frozen gases and other celestial debris that make up Halley's Comet when it reappears in the Earth's view in the winter of 1985-86. The Office of Technology has said that the space agency's lack of interest in a comet mission "puts U.S. scientists at a clear disadvantage with respect to the Europeans and the Soviets, both of whom will be flying such missions." Sagan has said: "There is the ominous and very real prospect that American leadership in planetary exploration will come to an abrupt end."[34]

Reflecting the rising interest in Halley's Comet, the Library of Congress recently published a listing of books and articles that already have appeared on the subject. The listing run to seven printed pages. There is even a *Halley's Comet Watch*

[33] Remarks in an interview broadcast on "The MacNeil-Lehrer Report," PBS-TV, Nov. 4, 1981.
[34] Quoted in *The New York Times*, July 19, 1981.

Newsletter.[25] The comet's sighting occurs every 75 years when it approaches the sun on its journey back from the outer reaches of our solar system. The Soviet Union, in partnership with France, is sending out two spacecraft, the Venera Halley 1 and 2, to witness the event at close range.

In December 1984 the spacecraft should come within 6,000 miles of the comet's solid nucleus and spend hours taking pictures and gathering data. In July 1985 the European Space Agency will launch the Giotto, which will fly within 100 miles of the comet. A Japanese spacecraft, the Planet A, will be launched the following month on the same mission.

Past Leadership in Planetary Research

The U.S. space program has long been the pioneer in scientific ventures. There have been dozens of unmanned exploratory probes over the years. In 1959, the Mariner 1 and 2 spacecraft circled Venus. The Pioneer series continued the space quest among the planets in the 1960s and 1970s. Pioneer 10 and 11, launched in 1972 and 1973, were the first spacecraft to visit Jupiter. Pioneer 11 went on to Saturn and in September 1979 returned the first close-up images of that planet.

Since 1979, the Pioneer Venus Orbiter has been circling Venus, studying its atmosphere, taking hundreds of ultraviolet pictures and radar-mapping its surface. Five Pioneer Venus probes have descended by parachute through the planet's atmosphere, sending data back to Earth for over an hour. From that information scientists confirmed their suspicion that Venus is a "hellish" planet, with a surface temperature about 900 degrees Fahrenheit, hot enough to melt lead. Pioneer Venus Orbiter will continue to operate through 1985, changing orbital paths.[26] Pioneer spacecraft operations and data analysis activities were terminated in September 1983, although limited operations necessary to the survival of the spacecraft were performed. In October 1986, Pioneer will become the first space probe to leave to solar system and travel into eternity.

Voyager 2, following its sister ship Voyager 1 to Saturn by a different trajectory, discovered in a region surrounding Saturn the hottest gas yet detected in the solar system. Voyager's instruments showed temperatures ranging from 600 million to

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[25] The listing appears in the *LC* [Library of Congress] *Information Bulletin*, Nov. 26, 1982, compiled by Ruth S. Freitag of the Library's Science and Technology Division. The newsletter describes itself as the "official publication of Halley's Comet Watch '86 . . . an international organization dedicated to the historical, scientific study of . . . Halley's Comet." Its address is Box 188, Vincetown, N.J. 08088.

[26] The Soviet Union also has sent probes to Venus. On Feb. 28 and March 5, 1982, two Soviet spacecraft landed on Venus, the seventh and eighth the Russians have landed on the planet.

more than one billion degrees Fahrenheit, about 330 degrees hotter than the Sun's corona. Like Voyager 1, Voyager 2 concentrated on Saturn's rings, but the spacecraft also studied Saturn's moons. It is now destined to reach Uranus in 1986 and Neptune in 1989 unless NASA decides to cancel those two visits.

NASA, in cooperation with West Germany, will launch the survey spacecraft Galileo toward Jupiter in 1985. Galileo initially was scheduled to go into orbit around Jupiter in 1987, but budget austerity will slow its flight. It won't reach the planet until 1989. A conventional upper-stage engine will be used to fire the spacecraft instead of the new, more powerful, hydrogen-fueled, high-energy Centaur engine, which would have enabled Galileo to fly a more direct path to Jupiter.

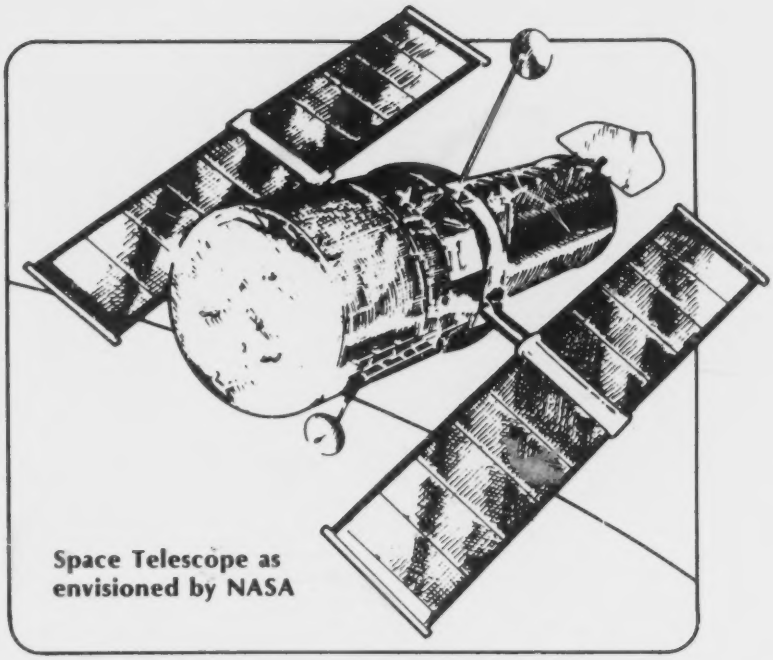
Telescope in Orbit and Earth Projects

Mankind will be able to peer farther into space than ever before when a gigantic telescope is sent above the Earth's atmosphere aboard a space shuttle and then placed in orbit. This log-shaped Space Telescope, 43 feet long and 14 feet wide and weighing 12 tons *(see illustration)*, is expected to remain operable well into the 21st century. With a view unhindered by the Earth's atmosphere, astronomers expect to see stars created 14 billions years ago, about the time of the creation of the universe, according to some scientific thinking.

The telescope's first important assignment will include observations of Uranus to help plan the course of the Voyager 2 flyby of Uranus in January 1986. The telescope will also help astronomers study Halley's comet, though from a greater distance that the European and Japanese probes. Some scientists predict that one of the first discoveries with the telescope will be that of another planetary system.

For all of the fascination with planets and other celestial bodies, the space program's focus these days is essentially upon the Earth and its immediate surroundings. A decade ago on July 23, 1972, NASA inaugurated its Landsat satellite program to collect information about Earth's resources by means of remote sensing instruments placed on a platform in space. The Landsat 1 satellite was followed by 2 in 1975 and 3 in 1978, both of which are still in service. Last July 16, NASA launched Landsat 4, equipped with high advanced scanning devices that provide greater clarity of detail.

The space agency plans soon to hook a device called SARSAT — Satellite-aided Search and Rescue System — onto a satellite so that distress signals from ships and aircraft radio beacons can be monitored. The monitoring will be conducted by the National Oceanic and Atmospheric Administration.



Space Telescope as envisioned by NASA

One futuristic concept on the drawing board is a space solar-power satellite. It would collect solar energy and beam it to Earth for conversion into electricity. But as-yet-unsolved technical problems and cost estimates that range between $1.5 trillion and $3 trillion have led the National Academy of Sciences to recommend that no funding be allocated to the satellite's development until the 21st century.

Envisioning 21st Century Space Colonies

By then, according to some of the more visionary notions of what lies ahead, may come mankind's first feeble efforts to establish colonies in space — until now only the stuff of science fiction. By the early 1970s Princeton University physicist Gerard O'Neill was seriously proposing that the world embark on a plan to place facilities in orbit capable of sustaining life for 10,000 — eventually one million — people. As portrayed in his 1977 book *The High Frontier: Human Colonies in Space*, these would be idyllic, spacious settings covered by transparent domes.

There are other scenarios which today seem far-fetched if no absurd. Yet considering how many of Jules Verne's 19th century insights became reality in the 20th century, people living in the last quarter of this century dare not scoff at predictions of what the next may bring. More than artistic achievement may account for the moviegoing popularity of "ET" and the readership of Arthur Clarke's *2010: Odyssey Two.*

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Why Billions Can and Should Be Spent on Space

By PAUL W. KEATON
Los Alamos National Laboratory

Over the next twenty-two years GNP will total about $100 trillion, easily supporting $130 billion for large focused space programs

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PAUL W. KEATON, (M), of the Los Alamos National Laboratory, conducts technology assessments in its office of planning and analysis. He joined Los Alamos in 1965 as a research scientist in nuclear physics. In 1972, he was a visiting scientist at the European Center for Nuclear Research in Geneva, and returned the following year to direct the Electronics Div. In 1980 he was appointed to a Pentagon study group evaluating U.S. nuclear weapons. Keaton received a Ph.D from the Johns Hopkins Univ.

"If we could first know where we are and whither we are tending we could then better judge what to do and how to do it." Abraham Lincoln[1]

Over the past 22 years the United States produced more income than in all of its previous history. The cumulative gross national product (GNP) from 1960 through 1981 was $52.7 trillion in constant 1982 dollars. The federal government spent 0.51% of that amount on our space program.

As a national investment, these expenditures on space can be considered successful. We depend increasingly on space for vital public services such as surveillance for treaty verification, remote sensing for finding resources, navigation for ships at sea, and weather reporting for nations around the world. In addition, members of the private sector are searching for more revenue-generating products and services in space similar to the lucrative communications-satellite business.

However, our national space program is undergoing a kind of "identity crisis" as the Shuttle goes into operation. This is similar to the post-Apollo slump suffered by NASA in the early 1970s before the inception of the Shuttle program. Having experienced this problem twice, should we not look ahead and seek long-range commitments for our space program?

Long-range commitments need not mean large financial outlays. The annual budgets can be any size so long as our society can afford them. To take a conservative approach, we may assume that the U.S. can "afford" to spend money on space activities as long as the per capita income is increasing. As it happens, that assumption does not represent a restriction on the analysis presented here.

To make practical long-range plans in either the public or private sector, we need to ask what kind of financial resources can be expected from the government and over what period of time. That is the purpose of this article.

U.S. Economic Trends: What has been the trend of the U.S. economy over the last century? F-1 shows our GNP in constant 1982 dollars from 1890 through 1981. (The numbers are taken from U.S. Dept. of Commerce publications.[2,3] The GNP implicit price deflator for 1982 is derived from an Office of Management and Budget publication.[4])

The most striking feature of the GNP since 1890 is its close fit to a single exponentially rising function,

depicted in F-1 as a solid curve. The least-squares fit to the actual constant dollar "data points" indicates that the average annual real growth rate of the GNP has persisted at 3.18% per year *despite all of the globally and nationally significant events that have taken place since 1890.* Diverse events having major political and economic consequences for the U.S. over the 92-year period include—

—The Great Depression of the 1930s.

—World War I and World War II.

—The advent of the New Deal in the 1930s (this included the abolishment of the gold standard in 1933, the establishment of Social Security in 1935, and the subsequent adoption of a mixed economy in which both public and private institutions exercise economic controls).

—Conversion of our nation's primary energy base from wood and coal to oil and natural gas (this was accompanied by the revolution of our transportation system from the horse and buggy to the automobile as well as the invention and commercialization of the airplane).

—Invention of the transistor, the integrated circuit, and the microprocessor.

—Invention and development of the liquid-fueled rocket engine used in the Apollo project to place men on the Moon in 1969 and subsequent technology spin-off.

—Assassination of President McKinley in 1901 and President Kennedy in 1963 and the resignation of President Nixon in 1974 under the threat of impeachment.

—Admission of 12 new states to the Union.

—The consolidated actions of the OPEC nations in 1973 that abruptly raised the price of oil.

—Emergence of the U.S. as a superpower with about one-twentieth of the world's population producing over one-fifth of the world's wealth.

Not one of these momentous events has left a distinguishable permanent imprint on the real growth rate of the GNP over the last 90 years! Rather, the effects of various events and developments have been compounded in such a way as to produce, on the average, a steadily increasing national income. This testifies to a certain robustness of our economy, whatever the explanation.

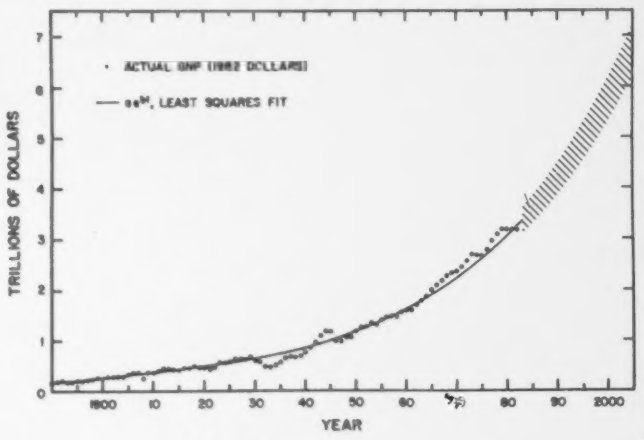
The exponential function of F-1 exhibits a "doubling time" of 21.8 years. (That is, $e^{bT} = 2$ for $T = \ln 2/b = 21.8$ years.) For instance, the 1959 GNP was $1,509 billion (in constant 1982 dollars) and it had slightly more than doubled to $3,153 billion 22 years later in 1981. This means that the total real income of the nation roughly doubled every generation, while the population increased by less than

T-1 CUMULATIVE U.S. GNP
Figures in billions of 1982 dollars

Beginning year (22-year interval)	Ideal[a]	Actual	Difference, b %
1894	$6,183	$6,673	7.9
1916	$12,444	$11,499	−7.6
1938	$25,045	$24,496	−2.2
1960	$50,406	$52,730	4.6
1982	$101,449	— —	— —

[a] Derived from exponential curve of F-1.
[b] Actual GNP minus ideal GNP divided by ideal GNP.

F-1 U.S. GROSS NATIONAL PRODUCT HISTORY
GNP since 1890 in constant 1982 dollars appear as dots. The line is an exponential fit with $A = 1.392 \times 10^{-34}$ dollars, $B = 0.0317$/yr, and t is in years A.S.

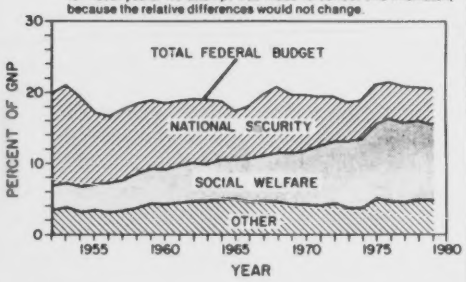


30%. One doubling time can be adopted as a natural unit of time for a "long range outlook" pertaining to U.S. economic perspectives.

Obviously the total GNP generated during any doubling-time period exceeds the cumulative GNP before that period. T-1 shows this actual accumulated GNP in constant dollars for four consecutive 22-year periods spanning 1894 to 1982 in an approximate ratio of 1:2:4:8. It also shows what the ideal cumulative GNP would have been, as calculated from the exponential curve of F-1.

For each of the consecutive 22-year doubling periods since 1894, the actual cumulative GNP varied from the ideal GNP by no more than plus or minus 8%. In addition, the ideal cumulative GNP for the next 22 years, starting in 1982, comes to

F-2 FEDERAL EXPENDITURES
Federal budget distributions as a percent of GNP since 1960. The GNP is given for the calendar year and federal budgets are given for fiscal years. No attempt was made to correct this mismatch, because the relative differences would not change.



$101,449 billion. It is adequate for present purposes to deal in round numbers and assume during the 1982-2004 period the U.S. will generate a GNP of $100,000 billion, plus or minus 8%, in 1982 dollars.

Federal Budget Trends: All U.S. space expenditures, like other government programs, are under constant and conflicting pressures from segments of the public, the military agencies, the private sector, the scientific and engineering communities, and political coalitions. Assume that space-program supporters will continue to fight for, and receive, the same fraction of their category of funding sources as they have fought for, and received, in the past. For our purposes, those funding sources must be identified in categories that are sufficiently narrow to distinguish among past budget trends and sufficiently broad to allow room for the statistical "give and take" of the budget process averaged over many years and several political regimes. To do this, we observe that space activities have been funded for the last 25 years mainly by NASA and DOD, and we identify the pools of federal money which supply their funds.

The federal budget constitutes less than 25% of our GNP. F-2 shows the 27-year distributions of federal-government spending as separated into categories of national security, social welfare, and "other."[2,3] These categories can be traced through the documents of the U.S. Dept. of Commerce. The sources of NASA funds are the "other" category, which has remained more or less a constant fraction of GNP, as shown in F-2. DOD spending on space comes out of the "national security" category, which has remained roughly constant over the last 20 years, since it has fallen by almost half as a fraction of GNP while the GNP itself has almost doubled. We can use these two trends—constant dollar and constant fraction of GNP—as guidelines to extrapolate government expenditures on space activities into the future. But first we need to ask how *far* into the future present trends can be expected to last.

How Long Will Present Trends Continue?: We can think of the GNP as the sum of a large exponentially rising component ae^{bt}, with a characteristic time of $1/b$, and a small modifying term that takes into account major events such as a worldwide depression or a world war. The average growth rate is then the sum of a statistically significant number of random and uncorrelated events, $b_i(t)$, such as the invention of the transistor (positive) and the influx of Japanese cars to the U.S. market (negative). The growth rate may be written $b=\Sigma_{i=1}^{n} b_i(t)$, for which the least squares search shows that, on the average b has been a constant over the last 90 years even though the components $b_i(t)$ have not been constant. It follows by analogy with physical systems that b cannot change rapidly over a period of time $1/b=31$ years. The validity of this reasoning for social systems is supported by the slow progress which results from major efforts to change population growth rates.

It is easy to show that if the average GNP growth rate changes slowly over 31 years, then the cumulative GNP is relatively insensitive to the growth rate changes. For example, we can represent b by a linear expression of time and show that a plus or minus 100% change in b over 31 years will cause less than a $\pm 10\%$ change in the cumulative GNP over the next 22 years. It is interesting that a 1982 projection of Data Resources Institute shows a U.S. GNP growth rate of 2.2-3.2% from 1982 to 1995. A recent Chase Econometrics study indicates a range of 2.4-3.5% in growth rates for the 1980s, and in 1979, the Townsend-Greenspan economic consulting firm gave 3.4% as the top of the range for

our nation's GNP growth rate in the 1980s.[5] It seems, then, diverse approaches, including the present one, are consistent with a U.S. GNP growth rate in the neighborhood of 3%. Once that rate is accepted as reasonable, our analysis is insensitive to slow variations from 3% in the future.

Short of catastrophic or disruptive events greater in magnitude than *anything occurring in the world during the last century,* the economic system possesses a certain "inertia." The empirical evidence in F-1, showing a persistent growth for almost a century, should cause us to be skeptical of any theory which predicts that the economy will do otherwise during the next doubling period.

The so-called "Limits to Growth" debate is a case in point.[6] W.W. Rostow has studied this matter as part of his thorough analysis of economic history on a grand scale.[7] He saw the extreme pessimism of the mid-1970s in the context of at least four similar periods in the last 190 years: 1790 to 1815, 1848 to 1873, 1896 to 1920, and 1936 to 1951. The last two periods occur within the time-span of F-1. Each time, the pessimism could be correlated with scarcity in a world business long-cycle. Rostow attempts to explain prices, interest rates, wages, income distributions, and investment patterns for each business cycle in terms of two major variables: the relative abundance or scarcity of various foodstuffs and raw materials, and the character of leading sectors in the major economies. Rostow draws the conclusion that each period of scarcity is accompanied by the coming of new supplies or development of new technologies.

How the nation copes with the present period of scarcity will affect our government's commitment to space programs in the next century. A society develops according to its expectations of the future. Those who view the future as a clash of the Third World's rising hopes with the Earth's scarcity of resources advocate no growth. Those who view the future as a challenge to our innovative and creative abilities advocate *growth* to increase the wealth of the world and *technology* to escape the limits to growth. In the past the latter view has always prevailed and turned out to be correct for our country.

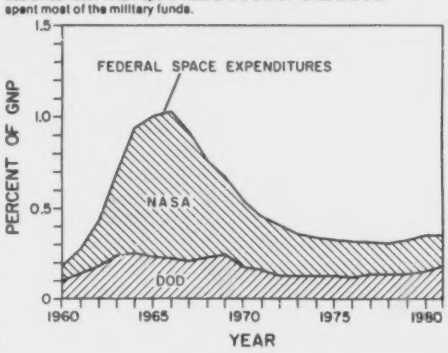
If this continues, before long we may need the extraterrestrial environment to develop both resources and manufacturing techniques.

From this perspective, and based on the historical precedence of four similar situations, it is likely that the American people will again choose the "growth scenario." But even if not, our economy is a going concern and the rate of growth can be expected to decline only slowly over three decades. As an extreme case, if we assume that the growth rate falls from 3% to 2% during the next decade, from 2% to 1% during the decade following that, and from 1% to 0% during the decade following that, the cumulative GNP between now and 2004 will be $90 trillion during the next 22 years. Based on today's population growth rate, it will still represent an increase of real per capita income for our country.

In other words, present trends are expected to change only slowly over the next three decades, and the U.S. can afford to continue the past patterns of spending on space activities even under extreme circumstances.

Future Space Funding: The actual distribution of federal funds for space activities (F-3) peaked at 1% of the GNP in 1966 and fell to 0.34% in 1980. The average rate of federal-government spending on space activities was 0.51% of the GNP between 1960 and 1980. The total was about $269 billion over 22 years in 1982 dollars.

F-3 **FEDERAL EXPENDITURES ON SPACE ACTIVITIES**
Civilian and military spending by the government on space activities since 1960. NASA spent most of the civilian funds and DOD spent most of the military funds.



Long trends in the U.S. economy and the federal budget suggest a number of ways to project future government spending on space activities, providing there are no drastic long-range changes in space policy. Some can be given as follows for a 22-yr period, the sums in billions of dollars:

Assumption	1982-2004 totals
Constant-dollar, point extrapolation	235
Constant-dollar, average extrapolation	269
1/3 DOD plus 2/3 NASA, average extrapolation	430
0.51% of GNP, average extrapolation	510
1% of GNP, point extrapolation	1,000

"The dangers of not making long-term commitments are two-fold: An unnecessarily miserly approach to our nation's space program can be a self-fulfilling prophecy, and without a long-range perspective we run the risk of spending the money unwisely by fits and starts."

The first line was arrived at by taking the total space budget of 1980—$10.7 billion in 1982 dollars—and multiplying that by 22 years to find $235 billion (one kind of "constant dollar" extrapolation). At the other extreme, multiplying the peak value of 1% times the cumulative GNP for the next 22 years ($100 trillion) yields $1000 billion (one kind of constant-fraction-of-GNP extrapolation). As estimates of future space budgets, $235 billion would appear to be too small and $1,000 billion too large, because both of these numbers are "point" extrapolations and are not extrapolations of decades-long averages.

Next, the constant 1982 dollar expenditures of $269 billion over the last 22 years can be taken as the amount that will be spent on space over the next 22 years. Or, using the constant fraction, 0.51% of the GNP over the past 22 years, we can multiply 0.0051 × $100 trillion to estimate that the U.S. will spend $510 billion on space activities during the next 22 years.

And finally, we can see that during the last 22 years a third of the U.S. space budget came under the heading of "national security" (through DOD), which experienced a constant-dollar budget for 27 years. The remaining two-thirds of the space budget came under the heading of "other" (through NASA), which experienced a constant fraction of GNP for 27 years. Therefore, based on these 27-yr averages applied to 22-yr spans, we can estimate that the future space budget will be made up of 1/3 × $269 billion (1/3 constant dollar) plus 2/3 × 0.0051 × $100,000 billion (2/3 constant fraction of GNP), or $430 billion over the next 22 years—all in 1982 dollars.

It would be difficult to choose which of these extrapolations is most likely to occur, although the last method, giving $430 billion, is the most faithful application of the guidelines. The figure $390 ±121 billion covers the range of most likely outcomes.

But the precision of these numbers is much greater than the range of uncertainty in the assumptions allows, and the numbers can be rounded without significantly affecting the accuracy of the estimate. This results in an estimate that the U.S. will spend $400 ±100 billion on space activities over the next 22 years. It must be understood that the uncertainty of $100 billion is not a statistical factor, but an attempt to bracket the range of the most likely occurrences.

The extreme no-growth case suggests that the U.S. economy would generate $90 trillion, instead of $100 trillion, if pessimistic assumptions come about. By that reckoning, the federal government would spend 1/3 × $269 billion plus 2/3 × 0.0051 × $90,000 billion = $396 billion on space during the next 22 years. The impact of those pessimistic and historically unrealistic assumptions is clearly in the "noise level" for our purposes.

During the past 22 years, the U.S. spent $70 billion on the Apollo program and over $10 billion on the Shuttle program (1982 constant dollars). This means that, of the $269 billion spent on space, about one-third can be attributed directly to large national commitments, one-third to military spending and one-third to other NASA missions, such as space sciences, technology development, and aeronautical engineering. If these trends continue, one-third of $400 ±100 billion will be "discretionary monies" for future national commitments.

This leads to the conclusion that over the next 22 years the U.S. can realistically make a national commitment to a major space program amounting to $130 ±30 billion. This would start out at about $4 billion per year and grow steadily to $8 billion per year in 2004 as the GNP doubles.

Concluding Remarks: Past experience often proves a better guide to future actions than projections based on "first principles."

We have observed that the average growth rate of the U.S. GNP has varied very little from 3.18% per year over nearly a century and that the growth rate consists of a statistical average of many uncorrelated phenomena. This suggests that the average growth rate will change slowly in a time of the order of 31 years. We deduce from this that economic trends which have lasted for three decades will change only slowly over the next three decades. Our results are obtained from a consistent application of these concepts.

An affordable space program was defined as one not so large as to keep the GNP per capita from in-

creasing. In that sense, all of the alternatives discussed here are affordable. In other words, the U.S. can afford a much larger space program than any mentioned herein.

Over the long term the U.S. economy looks robust. Barring unforeseen and unprecedented difficulties it will generate a GNP of about $100 trillion during the next 22 years, 0.4 ±0.1% of which is likely to be spent by the government on space. Past patterns of spending suggest that one-third of this $400 billion will be available for major national commitments to large focused space programs.

Even though this size of space budget was deduced by a conservative analysis, $130 billion over 22 years would fund a much larger project than today's politicians and administrators are willing to suggest publicly. The dangers of not making major long-term commitments are twofold: An unnecessarily miserly approach to our nation's space program can be a self fulfilling prophecy, and without a long-range perspective we run the risk of spending the money unwisely by fits and starts.

The U.S. can demonstrate leadership and sound stewardship of its resources by picking a long-range realistic goal in space and then developing the infrastructure necessary to achieve it. The goal should be chosen so that, as the program evolves, it derives economic, defense, political, and scientific benefits in dollars as well as in human satisfaction for the effort. Any goal fitting these criteria would be appropriate and provide continuity to our space program for decades ahead.

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BY SUSAN CHADWICK

What's Our Payoff from NASA Lift-offs?

Reproduced with permission of the copyright holder from Chadwick, Susan. What's our payoff from NASA lift-offs? Houston City magazine, v. 8, April 1984: 104-107, 124, 126-128, 131-133

NEW VISIONS, FAILED DREAMS

The Lyndon B. Johnson Space Center is located in the middle of a 1620-acre marsh prairie at the edge of Clear Lake just off Galveston Bay, an area distinctive only for its peculiar lack of distinction. The space center itself looks much like a large, pleasant community college, only here the "students" are mostly middle-aged men who wear identification badges on their shirts, and speak in acronyms, saying things like "OSS," "the LDEF on STS-13," and "PFTA in conjunction with the RMS on STS-8."

But there is something disappointing about the neighborhood surrounding the space center. Here, at the edge of the nation's headquarters for the manned spaceflight program, just outside the entrance to the place where astronauts are trained and which the whole world knows as "Mission Control," there is a common assortment of fast-food restaurants, chain stores, realty offices, shoe hospitals, hotels, and muffler shops. Only the long banks of low white buildings facing the space center grounds—the offices of aerospace and electronics firms which do much of the technical work at the space center—give the neighborhood a high-tech character.

True, there is prosperity where there was only empty prairie, which is what the Clear Lake area was 25 years ago. But there has always been the expectation—at least in the early years—that the space center would bring new high-technology industry to Houston, and that the industry's spin-offs would make the Clear Lake area Houston's answer to the high-tech communities emerging around San Francisco and Boston, and in North Carolina and other states.

It didn't happen.

In the last year, however, that expectation has risen again. After some 25 years of confusion over just what we were doing in space anyway, a practical purpose for being there finally exists: money. Now, at last, there appears to be a commercial market for space technology, and investors and businesses across the nation are taking an interest. A number of recent developments have contributed to this new interest.

The space shuttle can now provide reliable and regular transportation into space for

ILLUSTRATION BY DENISE WATT

commercial satellites, as well as for pharmaceutical, glass, and metal processing experiments with large profit potential. A permanent, staffed space station, as proposed by President Reagan in January, will provide a base for the shuttle and for astronaut crews. Orbiting space platforms will soon carry factories that will make the drugs and other materials now in the experimental stage. And the federal government has been encouraging private sector involvement, with tax shelters and cooperative agreements as incentives, thus opening up new fields for satellite development, satellite launching services, and other private space-tech enterprises.

What are Houston's chances for cashing in on this new industry? The space center is about the only thing the city has going—other than the Medical Center—which is not in some way connected to the oil and gas industry. Last year the Houston area lost almost 96,000 jobs largely because of the end of the decade-long oil boom. By comparison, between 1977 and 1981 the city gained just over 10,000 a year.

So Houston has a special interest in the Johnson Space Center, with its odd-shaped windowless buildings and towers sticking up here and there. What exactly is this place? What do people do there? And what are we supposed to do with it after all these years of viewing it mainly as a "celebrity acquisition," as one NASA official describes it, a great boost for Houston's image, and an interesting tourist attraction?

Is JSC supposed to be a growing industry which will provide thousands of new jobs? A research center that will develop new technology that will create new jobs? A talent pool of highly trained and educated engineers who will leave government service and start space-tech businesses?

"One thing we have to keep in perspective," says Lee Tucker, executive assistant to Houston Chamber of Commerce president Louie Welch, "when Columbus discovered America, he didn't come right over and start New York."

IN THE BEGINNING, we did expect something big to start here. The new manned spacecraft center was to make Houston a world-class city. Houston was now going to be something besides a cowtown with oil in the back pasture. It was going to be the portal to the future, to space, the new frontier. After Rep. Albert Thomas of Houston called up the Chamber of Commerce in September 1961 to announce that Houston had been selected as the site for the new space lab, the chamber gushed that "the new space laboratory will make Houston the headquarters of the most advanced technology in the world."

Houston had fought hard for the space lab, competing with seemingly better sites all over the country. The race to the moon was going to inject billions of federal dollars into the country's economy, and everybody wanted some of it. President John F. Kennedy was particularly keen to have the lab located in Boston, which already had plenty of engineers and scientists to work in it. Virginia politicians wanted the lab at the Langley Research Center, where the Space Task Group, about 75 engineers working for Project Mercury, was already in place. Others wanted the site in Louisiana, California, Florida.

Houston didn't have any scientists or engineers, or any supporting industry, but the warm climate was a plus, since the new lab would have to be constructed in a hurry. And access to the coast was thought to be important, though it turned out it was not.

What Houston really had that the fledgling National Aeronautics and Space Administration needed for President Kennedy's ambitious space program were the politicians. It also had some timely cooperation between a university and an oil company.

The most prominent politician, of course, was Lyndon Johnson, after whom the space center was renamed in 1973.

LBJ was "anxious" to have Houston be the site of the new space center, recalls former NASA administrator James E. Webb, now retired in Washington, D.C. And for LBJ's efforts on behalf of Houston, and on behalf of the space program altogether, he is amply memorialized in the JSC visitor center with an entire room filled with memorabilia—photographs, books, desk, chairs, flags, and significant documents.

At the time of site selection Johnson was vice president of the United States and also chairman of President Kennedy's National Aeronautics and Space Council. Before that, as Senate majority leader, he was chairman of the Senate Space Committee as well as chairman of the Preparedness Investigating Subcommittee of the Senate Armed Services Committee.

Johnson was important to the space center, but there were others, too. Down the hall from the Johnson exhibit at the visitor center hangs a color photograph of Congressman Olin E. Teague. "Tiger" Teague, after whom the visitor center is named, was a war hero and part of his district included the bay area. Teague was, by coincidence, chairman of the House Space Committee at the time the site for the new manned spacecraft center was selected in 1961.

The key politician, however, was Rep. Albert Thomas of Houston, then in his twenty-fourth year in Congress. Thomas, a shrewd and gentlemanly politician who wore bow ties and taught JFK the rudiments of Congress, was chairman of the House Appropriations subcommittee which passed on NASA's budget, as well as chairman of the subcommittee which appropriated any additional money needed by the space agency.

NASA needed Thomas' support. But it also needed 1000 acres of land with a university nearby, and Thomas helped with that, too. The university was supposed to

(continued on page 124)

SPACE CENTER

(continued from page 107)

provide research talent and educational opportunities for the young engineers who would be hired by the new space lab. Certainly any university located near the new center would benefit from the research dollars that would be flowing out of the laboratory.

The land upon which the space center now sits was then part of a 32,000-acre parcel belonging to the Humble Oil and Refining Company (now Exxon), which had decided that the property was too valuable for just grazing cattle, recalls John B. Turner, president of the Friendswood Development Company.

In the winter of 1961, about six months before the site for the new manned spacecraft center was announced, a meeting was held at Albert Thomas' office in Washington, D.C. According to the recollection of a retired newspaper publisher who was there, Jim Webb, the newly appointed administrator of NASA, said "Albert, we ought to get that space center in the southwest."

There followed a brief discussion of universities in the southwest. "How about Rice [Institute] in Houston?" said Thomas, a Rice graduate.

Though Rice Institute (now Rice University) was—and still is—basically a small undergraduate facility, Webb said he thought Rice might work, so Thomas called his old friend and classmate George Brown, longtime chairman of the Rice board of trustees and a founder of the engineering firm of Brown & Root, at Brown's Washington hotel suite. Webb, Thomas, and the newspaperman joined Brown for dinner, and on that evening, "So help me," says the newspaperman, "that damn thing—the site—was born."

"The skids were greased. Albert Thomas just picked that space center up and laid it in our laps."

In the months that followed, Rice beefed up its faculty a bit and added a Space Sciences Department, now the Department of Space Physics and Astronomy. It was said to be the first department of its kind in the nation, though NASA also helped to establish similar programs at other universities.

And, as a result of some swift but intense negotiations between George Brown and Morgan Davis, then chairman of the board at Humble, the oil company which donated 1000 acres to Rice, which in turn donated it to NASA. There would have been no tax benefit for Humble in donating the property directly to the government. NASA decided shortly after the agreement was signed ("The ink was hardly dry," recalls Malcolm Lovett, then counsel to the university) that 1000 acres wasn't enough. An additional 600 acres was needed, which Humble swapped to Rice for 100 acres of land near the Southwest Freeway. Rice then sold the 600 acres in Clear Lake to the government for about $2 million, according to Lovett, who in addition to being university counsel was then a member of the board of trustees. NASA also gave the university a grant of about $1.8 million to build a Space Sciences Building.

Houston needs a stronger university base to realize its technological dreams. "Dallas, Austin, Bryan, have stronger university bases than Houston," Stauffer says.

It was a happy deal for Rice, which got a new building and a new department. The Space Physics and Astronomy program now has 31 graduate students and 13 faculty members, and receives about $1.4 million a year from various sources—including the Department of Defense, the National Science Foundation, and the Welch Foundation—for space-related research. About

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$600,000 of that money comes from NASA in Washington, D.C., for work in areas such as satellite data analysis and the theory of the earth's magnetic fields. Rice does very little work for the Johnson Space Center, mainly because the space center itself does little theoretical or scientific research.

The NASA arrangement was also a happy deal for Humble, which formed Friendswood Development Company and had been developing part of the remaining 30,000 acres into Clear Lake City. The University of Houston also benefited, later receiving a donation of land from Friendswood to build a campus in the Clear Lake development.

Brown & Root won the $1.5 million contract to design the new $60 million space lab. Albert Thomas got a post office in Clear Lake named after him. And Houston got the astronauts, the engineers, and a whole new image as the center of the most advanced technology in the world. It was fun and exciting. And it was going to be the biggest thing to happen to Houston since the opening of the Ship Channel in 1915. But it didn't quite turn out that way.

THE SPACE SHUTTLE does not take off or land at the Johnson Space Center, as is often thought. Nor are space rockets designed or built there. The space center is, rather, a headquarters, a coordinating facility for that part of the national space program which involves astronauts.

As an industry it has never been a major employer. There are about 9000 people working there, compared to 38,000 at the Texas Medical Center, for instance. Peak employment occurred in the late 1960s, just before the first astronauts stepped onto the moon and promptly lost the interest of the public and the support of the politicians, sending the space program into a tailspin from which it is just now recovering.

There are now about half as many people working at JSC today as there were at the peak of the space program, and few of them have the advanced degrees that are the foundation of a research center. Out of 3399 government employees at the space center, about two-thirds are scientists and engineers, and most of them only have undergraduate degrees. Only 524 federal employees at the space center have Masters degrees, and 143 PhD or LLD degrees.

The Johnson Space Center is not a research facility, although it does have a small aeronautics research program which last year spent about $15 million developing new systems for the shuttle and studying ways to design and use the space station. Much of that work was contracted to private industry outside the state.

Though some of NASA's nine other major facilities are research-oriented, particularly in satellite and rocket technology, JSC has always had a management role, as the manned spaceflight program itself has always been more of a management problem than a technological problem: how to manage hundreds of thousands of people working on hundreds of different tasks at numerous different firms all over the country, make it all come together on time and work. The triumph of JSC is really a triumph of management technique.

Overall, the main task of JSC, which receives 30 percent of the total NASA budget of some $7 billion, has been to coordinate research and development taking place in other parts of the country, primarily in those areas which had the technology and industry twenty years ago, and still have it.

Last year, for instance, NASA paid Texas firms or firms with employees in Texas $454 million, of which approximately half went to astronaut training, research, maintenance, and work in mission control, and other technological programs in support of the space shuttles Columbia and Challenger. By comparison, firms in the state of California, where the aerospace industry is headquartered, received $2.3 billion, of which about half went to Rockwell International in Downey for designing, developing, and testing the space shuttle orbiter. Florida businesses received $651 million.

Overall, of money spent by the space center itself (not by NASA as a whole) in fiscal year 1982, Texas received about 20 percent of the total business contracts.

Of the $18.7 million paid to educational and non-profit research institutions, almost 40 percent went to Massachusetts, 33 percent of it to the Charles Stark Draper Laboratories in Cambridge.

California received the next largest amount, almost thirteen percent of the total, with five percent of that going to the California Insitute.

Texas institutions ranked third with twelve percent of the total. Half of that went to Texas A&M and most of the rest was spread out between Baylor and the University of Texas medical schools in Houston and Galveston, as well as UT branches in Dallas, Austin, and San Antonio.

The University of Houston at Clear Lake City received only .53 percent--$92,600.

SO THE JOHNSON Space Center is probably not going to serve Houston as a high-tech research center. What about the space industry itself? How much of that might Houston get?

Clearly, Houston has come a long way since the NASA layoffs in the early 1970s, when the moon mission had been completed and JSC engineers were supporting themselves making purses and selling fishing tackle.

"Nobody left the space program voluntarily in the early days," says J.L. Taylor, director of the Houston Chamber of Commerce's Economic Development Division. "The difficulty was nobody could figure out what to do [outside the program].

"When NASA started laying people off in the early Seventies, a lot of these people couldn't find jobs. And part of the problem was that what they were involved in was so esoteric, so far out, that private industry couldn't relate to what they had to offer."

That picture has changed somewhat, but JSC engineers still complain that business people don't understand what they are talking about. "Quite often I am accused of not being in touch with reality, of being a space cadet," says one engineer.

Still, there are new job opportunities for engineers who want to leave the space program. Few do. Working for NASA still has charisma. But, "there is money to be made in working for aerospace companies on payload integration--making sure the satellite won't come loose on the space shuttle, for instance," says one NASA engineer, who adds that recently, for the first time ever, private firms have been offering him jobs.

Other than payload integration, which is working with satellite and materials processing firms which want to use the shuttle ("payload" refers to the revenue-producing or useful cargo of the shuttle), there are three basic areas of opportunity for growth in the private space industry. They are in remote-sensing and communications satellites, satellite launching services, and materials processing-- manufacturing drugs, metals, and fiber optics in the low gravity of space.

What are Houston's chances in any of these areas?

The Johnson Space Center's expertise is not satellites or rockets. The satellite and telecommunications industry is already well established in California, which in addition to having a state space agency, also has the Jet Propulsion Laboratory and most of the aerospace and electronics industry. "California is very active," says Greg Fawkes of the Space Enterprise Project, a research foundation affiliated with the U.S. Chamber of Commerce promoting commercialization of space.

There is some hope that pharmaceutical companies and other materials processing industries might want to locate here in order to be close to the space center as it receives information from the astronaut crews conducting experiments on shuttle flights. At least one pharmaceutical company reportedly has plans to move to the Clear Lake area. However, it is not yet clear why it should be necessary for such firms to locate here, since the same information could be available almost anywhere.

There is, though, considerable excitement and attention focused on some of the now-retired stars of the Johnson Space

Center and what they might produce in some of the areas of satellite and launch services and industrial space vehicles.

"I think that the expectations for the return to the city of Houston were too high," says the Chamber of Commerce's Jay Taylor. "Not too high, but expecting returns overnight. In any high-tech development there is an average of ten to fifteen years before it gets to commercialization.

"We've had too much of a focus on the physical facilities. The location. That misses the point. The real asset to Houston was the people," says Taylor. "Most of the people in the program were very young engineers. Now they've matured, put down roots. They've become Houstonians.

"Twenty years from now, people like Deke Slayton and Max Faget will be chairmen of the boards of major corporations."

Deke Slayton and Max Faget are two of the luminaries of the space program, part of a small constellation of retired JSC managers now pioneering private space-tech businesses in Houston. These companies are in the early development stage, and there is a great deal of excitement about them, although, as Taylor points out, it will be a decade or more before we can expect many jobs to result.

Slayton, one of the original seven astronauts chosen for the Mercury program and later assistant program manager for the space shuttle, is now president of Space Services, Inc., of America, a company formed by Houston developer David Hannah, Jr. in October 1980. Space Services, Inc., which in 1982 wowed a great many people with the first launching of a privately financed rocket, the Conestoga 1, over the Gulf of Mexico, is in the satellite-launching business and plans ultimately to launch its own remote-sensing satellites. Slayton and Hannah don't have any customers yet, but in the meantime their company is working on its satellites and payloads.

Faget, a 35-year veteran of NASA and its predecessor, the National Advisory Committee for Aeronautics, is former director of engineering and development at JSC and the innovator of the Mercury spacecraft, director of the design team for the Apollo program, and preliminary designer of the space shuttle. Faget is now head of his own company, Space Industries, Inc., which he describes as "a very, very high-risk thing" which he has to sell to "a few people willing to invest in it... people looking for high-tech things to do."

Faget is hoping to put an industrial space platform into orbit which would be visited from time to time by the space shuttle. The facility would manufacture pharmaceuticals, fiber optics, and other processed materials in the micro-gravity of outer space. Johnson and Johnson plans to have a similar manufacturing facility in orbit by 1986. Faget's platform is just out of the design stage and he is still looking for funds.

There are other lesser luminaries now retired from the space program and active in Houston. Owen Morris, for instance, the manager of the Apollo program, has started a small firm, Eagle Engineering, with a full-time staff of about twenty, on El Camino Real in Clear Lake City. Max Faget is one of five vice-presidents and is in new systems development. Eagle Engineering provides management and technical services to mainly aerospace companies.

Dick Johnston, former director of Life Sciences at the space center, is now vice president for program development at the Texas Medical Center and works with the Houston Area Research Center in The Woodlands. Johnston is working hard to prod Houston into capitalizing on the medical technology and research which has come out of the space center, largely as a result of its role in monitoring the responses of astronauts to outer space. This is probably one of the only areas in which Houston has a unique advantage in the space-tech field. But how to translate this new technology into investment and business opportunities and products that are made here remains a problem for the city.

President Reagan's stated goal to promote commercialization of space and build a space station within the next ten years has given an additional boost to the city's hopes for a new high-tech industry to create new jobs. Those hopes intensified with NASA's February announcement that the Johnson Space Center would be the headquarters for the development of the space station, which is not to be as large a program as the space shuttle. Officials at JSC do not expect to do any hiring, and research and development funds will likely flow to other states as they have in the past. At the very least, however, the space station means greater stability and continuity for the space center.

As for space business, "Houston is very active," says Fawkes; pointing as an example to the Space Foundation, a Houston organization devoted to funding space-tech research and to promoting information exchange between investors and space specialists. But other areas are active, too. "Nationally a number of firms are springing up which want to develop new products and services and new transportation.

"At this point in time the advantage is going to go to the area that puts it all together—talent, money, good ideas."

"A deliberate effort of creating a thing is what it takes to develop high-tech research and industry of any kind," says Tom Stauffer, chancellor of the University of Houston at Clear Lake and chairman of the Houston Chamber of Commerce's Economic Diversification Planning Committee. Stauffer believes that the major benefit of NASA here is as a magnet to other engineers. NASA, he says, was not created for jumping full-blown into new industries.

Houston needs a stronger university base, too, if it wants to realize its technological dreams. "Dallas, Austin, Bryan, have stronger university bases than Houston," Stauffer says. "Rice needs to look beyond its own walls."

The city needs to develop venture capital expertise outside of the energy field, adds Stauffer. It needs to solve its transportation problems; develop cooperation among local industry, universities, and government and set up a committee, a plan, a goal, as other states and cities have been doing for years. George Mitchell has been doing this with the Houston Area Research Center in The Woodlands, north of the city.

THE OFFICES OF Gerald Griffin, director of the Johnson Space Center, are on the ninth floor of Building 1. From the windows of his office you can see most of the space center campus: mission control; the moon rock laboratory; the space food and space suit labs; the green towers of the noise and vibration testing facility; the building where the astronauts, now 75 of them, have their offices and classrooms.

Griffin is a Texan and a graduate of Texas A&M. A former flight director at the space center, he is trim and compact, not very tall, with smiling blue eyes. President Reagan had not yet announced that he would propose to Congress an $8 billion program to build the space station, but Griffin was obviously in a happy mood.

The Johnson Space Center is "not the panacea" for Houston's problems, says Griffin. "It's just a piece of the puzzle. But I think the business that is generated around space activities could be a major factor in the puzzle for the Houston area."

The space center will provide "a focus" and "a reason" for high-tech companies to develop here, "a rallying point for this area."

And there is still the image benefit. "The people of Houston don't look upon anything as impossible," says Griffin, beaming. "The moon mission and the whole space endeavor fit that, and I think people tend to migrate here because that spirit's here."

There are grand opportunities in space which most likely will benefit other parts of the country more, just as they always have. Houston has some space-tech resources to draw on, if it can figure out how. Certainly there is a willingness and excitement about doing that. But it does not appear that space business is going to become a major industry for the city.

"We need to concentrate on our strengths," says Texas Commerce Bank economist Carol Bennett. "Houston needs to figure out what its assets and liabilities are and work with them." ●

The Heritage Foundation Backgrounder

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WANTED: A SPACE POLICY TO DEFEND AMERICA

INTRODUCTION

In his address of March 23, 1983, President Reagan directed a "comprehensive and intensive effort to define a long-term research and development program, to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles." The media quickly, but inappropriately, characterized it as the "Star Wars" initiative.

The message was clearly directed at goals rather than means. The technological basis for this fundamental policy shift involves new technology and innovative concepts in space. Prevailing military space policy does not explicitly provide the clear directives needed to support the President's initiative. It is now essential, therefore, to reexamine and revise U.S. military space policy.

BACKGROUND--SPACE IN NATIONAL POLICY

Present military space policy is set within the framework of national space policy, which was first established by the National Aeronautics and Space Act of 1958. While the NAS Act encompasses the civilian and military aspects of space, the specifics of the act deal mostly with the establishment of the civil space program and the organization of the National Aeronautics and Space Administration (NASA). It was intended to project the peaceful and scientific objectives of the space program to the world community.

The NAS Act set forth the basic national policy for a vigorous U.S. response to the Soviet space challenge. It established executive authority for a new class of programs that did not fit existing civilian agency structures. Congress

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recognized that the technical skills and resources needed to achieve meaningful results would necessarily draw on the same industrial skills that supported military development programs.

The NAS Act is explicit in assigning the responsibility for "activities peculiar to or primarily associated with the development of weapons systems, military operations, or the defense of the United States..." to the Department of Defense. It contains no language that excludes or prohibits military use of space for national defense. The governing principle is that military space policy derives from national defense policy, consistent with U.S. laws and treaty obligations.

The basis for a military space policy consistent with international law is derived from the right of all nations to self-defense, a long recognized principle. Within this framework, military activities in space are constrained by specific treaties, principally the 1967 U.N. Outer Space Treaty and the 1972 Anti-Ballistic Missile (ABM) Treaty.

The Outer Space Treaty contains explicit prohibitions against stationing in outer space any object carrying a nuclear weapon or any other weapon of mass destruction, although there are no provisions for verifying treaty compliance. It further prohibits establishing military bases and testing weapons on celestial bodies. Neither of these prohibitions is an impediment to the development of U.S. military space policy, space operations, and new kinds of space weapons currently being considered for deployment. For example, space-based high energy lasers or particle beam weapons are not considered "weapons of mass destruction" and so are not covered by the Outer Space Treaty.

Unlike the U.N. Outer Space Treaty (an agreement signed by more than eighty countries), the ABM Treaty is a bilateral agreement signed in May 1972, by the United States and the Soviet Union as part of SALT I. This treaty restricts the development and deployment of ballistic missile defense systems, specifically including space-based systems. The Treaty does permit research and development on ballistic missile defense technology. Furthermore, the United States went on record that failure to achieve more comprehensive strategic offense arms limitations within five years (of the date of signing), could constitute a basis for withdrawal from the ABM Treaty.

There are several reasons for questioning whether the United States should continue to be bound by the ABM Treaty.[1] However, in any event the Treaty does not preclude a military space policy that includes the conceptual development, and supporting research and technology for space-based ballistic missile defense systems.

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[1] See the Heritage Foundation publication, "A Time to Revise the ABM Treaty," in National Security Record, No. 49, September, 1982.

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PRESENT U.S. MILITARY SPACE POLICY

Present U.S. military space policy derives from the national space policy announced by President Reagan on July 4, 1982.[2] It closely parallels the policy developed under the Carter Administration, and reaffirms the national security basis for a military space program. The United States has consistently endorsed the use of space for national defense.

The most recent review of military space policy recognizes that space activities support such important military functions as command and control, communications, navigation, environmental monitoring, warning, surveillance, and space defense. The policy directs that future U.S. space programs move toward operational capability. This orientation places importance on the ability of space systems to survive and endure under wartime conditions. In addition, the policy explicitly directs the continued development of an anti-satellite (ASAT) capability with two objectives. The first is to deter attacks on U.S. satellites. The second is to have the ability to attack the space assets of an adversary in time of war.

President Carter endorsed the development of an ASAT weapon in Presidential Directive-37, which spelled out U.S. military space policy. The ASAT weapon development was undertaken in 1978 in response to continued Soviet development and testing of such a weapon.

This program represented a distinct departure from previous military space developments; for the first time since the 1960s, the U.S. undertook a space weapon development program. This program was announced concurrently with the initiation of talks with the Soviet Union on limiting the deployment of ASAT weapons in space. U.S. military space policy reluctantly embraced the development of a single space weapon aimed primarily at matching a Soviet capability. The development of weapons for ballistic missile defense, however, would not have been encouraged by the Carter policy.

As the executive agent for military space activities, the Air Force is the principal architect of U.S. military space posture. Air Force doctrine describing military space operation is stated in Air Force Manual 1-1. This delineates three types of space operations: space support, force enhancement, and defense of space assets.

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[2] Present U.S. space policy is the result of an interagency review requested by the President in August 1981. While some of its details remain classified, the essential thrust of the policy is contained in a White House Fact Sheet on National Space Policy, dated July 4, 1982. The military aspects of the policy are outlined further in a Department of Defense Fact Sheet on DoD Space Policy, dated August 11, 1982.

Space support operations involve the construction and operation of facilities shared by a number of military users. The most visible of these are the launch complexes that put military spacecraft into space. In addition, facilities like the Satellite Control Facility provide support to military satellites in orbit. Other radar and optical tracking stations feed satellite data to the Space Computation Center inside Cheyenne Mountain, near Colorado Springs. These facilities provide surveillance over all space activities, including the orbiting of non-U.S. satellites.

Force enhancement describes the military satellite programs that support ("enhance") other traditional military functions. These programs do not directly involve weapons; they provide information and communications for the more effective command and control of military operations.

Reconnaissance satellites provide critical data on Soviet force levels and disposition, facilities, and weapon characteristics. They are the key element in verification of arms limitation agreements, the "national technical means" cited in the SALT agreement. The satellites of the Defense Support Program maintain a continuous surveillance over Soviet missile launch areas, to warn of attack and signal the launch of Soviet spacecraft. Satellite-borne detectors also signal nuclear detonations. A system of military satellites provides worldwide weather observation. These and other observation satellites provide a capability to monitor events on a worldwide basis that would not be practical by any other means.

Military satellites provide effective communications to U.S. forces around the world. Continuous quality communications service is provided to key U.S. installations overseas. These systems extend reliable communications to sometimes remote foreign areas. They also insure that the communication links are under U.S. control. In crisis or rapid deployment situations, communications at new locations can be quickly established. The Defense Satellite Communications System provides heavy route backbone communications on a worldwide basis.

The Fleet Satellite Communications System provides reliable communications to Navy tactical units at sea. The Air Force Satellite Communications system provides a more survivable means of commanding a retaliatory strike in the event of nuclear war. The Global Positioning System will provide military units the ability to accurately determine their position on a worldwide basis at any time. The new Milstar system will greatly increase the survivability of key military communications links and enhance their ability to work effectively in the presence of jamming. Military satellite communications are important to enhancing the ability of U.S. forces to operate effectively anywhere in the world.

Space defense (defense of space assets) is the third category of space operations. It is a set of missions established in 1978, with the space policy delineated in PD-37. The space defense mission includes the development of the U.S. anti-satellite system, the surveillance and tracking of all objects in space, measures to protect U.S. satellites and increase the survivability of space systems, and the command and control of the space defense mission.

By establishing these programs, the United States took action in response to the evident Soviet capability for attacking U.S. military satellites. At that time the U.S. lacked the capability to directly respond to a Soviet attack on its space assets. In the event of such an attack, it could either respond by other military means, risking a broadening military confrontation, or do nothing. U.S. military options for responding to Soviet attacks on U.S. space assets remain the same today. The program to field a U.S. ASAT weapon has yet to reach the final stages of testing. In the meantime, the risks associated with undefended space assets have increased with the growing use of space systems in U.S. military operations.

SPACE DOCTRINE AND MAD

Air Force space doctrine has been structured to support current U.S. defense policy. Strategic deterrence policy has long been built on the capability to deliver a devastating retaliatory blow in response to a Soviet nuclear attack. The policy of Mutual Assured Destruction (MAD) has placed the greatest priority on building and maintaining the readiness of the forces necessary to deliver the offensive counterstrike.

The missions spelled out in Air Force space doctrine are designed to support the offensive weapons systems that are the backbone of U.S. strategic defense policy. The Air Force reconnaissance mission keeps tabs on Soviet missile launchers and provides accurate targeting information. The surveillance mission provides warning of the launching of a missile attack, and information on the expected targets. Satellite communications provide essential links to collect surveillance data for processing and assessment, and for dissemination of Emergency Action Messages to the retaliatory nuclear strike forces. The missions spelled out in Air Force space doctrine are designed to support the offensive weapons systems that are the backbone of U.S. strategic defense policy.

Even the U.S. ASAT program is aimed at deterrence by retaliation. It provides only very limited defense of U.S. satellites in space. It is intended primarily to assure the Soviets that an attack on U.S. space assets could be met in kind with a counter-attack.

Air Force space doctrine also supports the policy of MAD by what it does not provide--a role for ballistic missile defense. Even the task of conducting anti-ballistic missile research, which is permitted under the terms of the ABM Treaty, has been assigned to the Army, and this effort has been centered on defense of hardened strategic assets against Soviet warheads in the final stages of their flight.

In not providing a ballistic missile defense mission, Air Force space doctrine has adhered to U.S. strategic policy of MAD, and the delineation of service roles and missions by the Department of Defense.

The concept of deterrence through Mutual Assured Destruction requires that the U.S. and the U.S.S.R. have the capability to destroy each other as viable societies. This concept (expounded by Robert McNamara in 1962), became the basis for U.S. strategic policy. It was this policy which guided the U.S. position in the Strategic Arms Limitation Talks.

The MAD concept requires that neither side have an effective ballistic missile defense system. Such a system would disrupt the balance of nuclear force levels that the SALT I Treaty sought to establish. Hence, the negotiation of the ABM Treaty became linked to the negotiation of ceilings on offensive nuclear forces. Given rough equivalence of force levels and no effective ballistic missile defense, the MAD concept holds that the cities and populations of each country are held hostage to the other side.

Within the numerical force levels permitted under the SALT agreement, the Soviets developed and deployed a new generation of ICBMs with greatly increased accuracy. These missiles have made large segments of the U.S. nuclear deterrent vulnerable to a Soviet first strike. There is no evidence that the Soviet Union ever subscribed to the concept of MAD. On the contrary, their writings on strategic doctrine have emphasized the merits of a massive use of nuclear weapons against U.S. nuclear retaliation forces, and the advantage of a surprise preemptive strike.

Along with their build-up of strategic nuclear forces, the Soviets have continued to strengthen their defensive systems. While the United States all but abandoned development of ballistic missile defense systems, the Soviets upgraded ABM defenses. These measures have exploited loopholes and, in some instances, violated the ABM Treaty.[3] At the same time, the Soviets have continued to devote substantial resources to civil defense.[4] The clear evidence indicates that the Soviets have

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[3] See Senator Steven Symms (R-Idaho), "Soviet Violations of ABM Treaty," Congressional Record, April 14, 1983, pp. S4625-S4627.

[4] According to the Central Intelligence Agency, the U.S.S.R. is spending about $2.5 billion a year on civil defense. The U.S. spent $147 million for civil defense in FY 1983.

been striving for nuclear superiority. The MAD concept has not worked.

The MAD framework for U.S. strategic policy was established in the early 1960s. The technological basis for this policy is more than twenty years old. Since that time, technology has advanced markedly in a number of areas. Space missions that were then only concepts near the limits of further expectation now are routine. The U.S. posseses the know-how to build space systems that can be moved and pointed with extreme accuracy, and to acquire and track objects in space. The U.S. has developed small data processors that are the equivalent of what was then a room full of computers. And the U.S. can build weapons effective over the vast distances of space.

Over the years, the application of these advances in technology has been encouraged in those areas that support underlying strategic policy. Advances that tend to undermine the technological foundation of this policy have, at best, not been fully exploited. Under the MAD policy, the United States supported vigorous development and deployment of offensive weapon capability. After the initiation of the SALT process, only minimal support was given to ballistic missile defense technology. The potential of new technological approaches to ballistic missile defense in space has been further thwarted by the lack of a meaningful Air Force mission in ballistic missile defense. Such a mission makes little sense as long as the U.S. continues to cling to a strategic policy based solely on MAD.

NEED FOR A REVISED SPACE POLICY

There is nothing in the National Aeronautics and Space Act that prohibits the development and deployment of weapons in space. If there is a failure to exploit the full capabilities of space for national defense, it is traceable to the policies the United States has chosen.

Intercontinental ballistic missiles (ICBMs), once launched, have been seen as invincible weapons. Rather than attempt to devise a direct defense against ICBM attack, the United States has chosen to insure a devastating retaliatory attack as a deterrent. It has devoted resources and technology to achieving diversity and dispersal of nuclear forces to assure that the retaliatory blow can be delivered. Now the high accuracy of the newer Soviet ICBMs and increasing numbers of submarine launched ballistic missiles (SLBMs) have cast grave doubt on the survivability of two of the three components of U.S. strategic forces. The perceived strategic stability achieved under the MAD doctrine already has been shattered.

At the same time, the United States has failed to pursue vigorously the search for alternatives that might some day offer the promise of an effective defense against ballistic missile

attack. The essence of the Defense Technologies Study initiated by President Reagan is a plan that will direct the best technical resources toward a more acceptable solution to the strategic defense problem. It involves new concepts for systems in space.

It has long been recognized that the most vulnerable portion of the flight of an ICBM is the boost into orbit, when the large rockets are already stressed by thrust and vibration. Any defensive attack on ICBMs during this phase necessarily involves overflight of the Soviet land mass and that can only be accomplished by defensive space-based weapons. The mid-course portion of a missile flight takes place in space.

Any attempt to destroy a missile during this phase implies an attack in space. This holds whether the defensive weapon is based on the ground or in space. The boost and mid-course phases consume most of the total flight time of an ICBM, where the destructive weapon is the most distant from its target.

The Department of Defense has spent over $1 billion on direct energy weapons. By far the largest amount has been spent on the development of high energy lasers. Most of the money has been spent on developing the basic technology needed to build practical weapons and on research on the physical mechanisms involved. The technology includes building lasers capable of megawatt power levels, large optical systems to form beams, and pointing and tracking systems of extraordinary accuracy to direct a beam and hold it on target. It includes experiments to determine the effects of the atmosphere on the beam and the damage effects on optical surfaces and target materials.

High energy lasers can be built and made into effective weapons. More development work is needed to assess the cost and effectiveness of particular applications of these new weapons in comparison with more conventional weapons. These comparisons can only be made when the laser weapon is designed to perform a particular military mission.

The military applications are structured from the missions of the services. The Army is investigating the effectiveness of laser weapons for short range battlefield use and air defense. The Navy's interest has focused on fleet defense against aircraft and missiles. Much of the Air Force effort has been centered on the operation of an airborne high energy laser suited to Air Force missions. The substantial Defense Advanced Research Projects Agency (DARPA) Triad program, although suited for space application, has been on non-mission oriented technology development.

The application of this technology to space missions is lagging, in part because of an insufficient statement of mission requirements. The mission requirements are lacking because of a defense policy focused heavily on strategic offensive capability.

The technology "push" for ballistic missile defense in space is evident. The mission requirements "pull" for the application of that technology has been absent.

The most vocal support for moving ahead on military applications of space-based high energy lasers has come not from the Air Force but from Congress and the General Accounting Office. Senator Malcolm Wallop (R.-Wyo.), a strong supporter of space-based lasers, pointed out that "Since 1981 the Senate has voted twice, by 91 to 3 and unanimously, to tell the Department of Defense to build a space-based laser weapon as quickly as possible.... But...neither the necessary funds nor the essential direction have been brought to this area."

The strongest and most detailed case for a new national strategy incorporating a strong ballistic missile defense program has come from High Frontier, a non-profit organization, headed by Lt. Gen. Daniel O. Graham, USA (Ret.). It has not come from the Department of Defense or closely allied sources.

The orientation of U.S. military space policy and the Air Force Space Doctrine that derives from that policy are significant contributors to the lack of requirements pull. Lack of organizational focus has contributed as well. Prior to the activation of the Air Force Space Command in September 1982, there was no single organization within the Department of Defense with responsibility for the development and operation of space systems. This responsibility was spread over at least four major Air Force commands, with other Air Force, Navy, Army, and Defense agencies participating in particular aspects of space.

The establishment of the new Space Command should be only an interim step toward the formation of a separate military service, with responsibility for space as a military realm, on an equal footing with land, sea, and air. The critical deficiency has been a lack of advocacy for space missions outside of the framework of established Air Force doctrine.

The Air Force has recently moved to amend its space doctrine to accommodate a broader range of space missions. Under the more recent doctrine,[5] a new mission category has been added, called "potential warfighting missions." In this doctrine, the name of the mission of space defense appears to have been replaced by "space control and superiority." In addition, a broad range of potential missions for space-based weapon systems has been added. Included is the statement that, "Such systems could be able to provide target damage against widely distributed and increasing numbers of enemy counterforce and countervalue surface targets." Unfortunately, the language does not make it clear whether this language is intended as a broadening of Air Force space doctrine

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5 Military Space Doctrine, Air Force Manual 1-6, 15 October 1982.

to support new strategic ballistic missile defense initiatives. The potential shift in doctrine must be clearly and unambiguously reflected in stated U.S. military space policy. The new Air Force doctrine must have the necessary foundation at the national policy level.

CONCLUSION

Space policy alone is not the issue. The present space policy is designed to support an obsolete strategic policy. In this context, President Reagan's address of March 23 laid the political foundation for a return to the traditional concept that the military should defend the country against attack.

If advanced technology in space holds the promise of an effective defense against nuclear attack, then the achievement of that goal is inhibited by a number of barriers. Some of the barriers are technological and cannot be overcome without determined effort. Other barriers lie in policies of the U.S.' own choice. These can and must be changed. One positive step would be support for a new space policy that seeks legitimate opportunities in space to achieve an effective ballistic missile defense.

Prepared for The Heritage Foundation
by C. Richard Whelan,
a Sunnyvale, California, based
consultant on space defense and
military Command, Control, Communications and Intelligence

CHAPTER FOURTEEN

SPACE PROGRAM BENEFITS

I. STUDIES OF THE ECONOMIC EFFECTS OF NASA R. & D.

By David Bruce Hack
Analyst in Science and Technology

A. Introduction

Some would say that all manner of U.S. national problems—ranging from energy supply, to inflation, to loss of confidence in the dollar abroad, to urban youth unemployment and environmental protection—may perhaps be solved by liberal applications of space research plus technology transfer. The opposite extreme view is that space research and technology development is a waste of money that could be spent more directly on the solution of problems which press directly. NASA has addressed this polarization of view by seeking a more scientific basis for estimating the non-mission net social benefit of NASA programs. The purpose here is to review the principal reports resulting from this NASA-sponsored effort—together with a General Accounting Office (GAO) assessment of one of those reports—and to comment on a scattered few studies by aerospace industry authors.

The literature review here on economic effects of NASA's R&D can be divided into three categories: (1) short-run effects on the national economy arising from increased demands for goods and services; (2) long-run effects arising from increased supply of goods and services; and (3) case studies and sectoral/regional economic effects studies intended to support by illustration the effects of types (1) and (2).

B. Short-Run Demand Effects—The Chase Study

It is commonplace to read discussions in the print mass media of the effects of Government spending on aggregate demand and gross national product (GNP). This is testimony to the wide acceptance and public application of the economic ideas derived from John Maynard Keynes over the last 40 years. Such effects of Government spending are in fact so widely discussed that they may be the only effects thought of by some whose acquaintance with economic thought is casual, or only through mass media. Other effects will be taken up in a subsequent section. In order to clarify what is at stake, however, this section will first discuss the effects which may be closest to the mind of the serious newspaper reader who is otherwise unacquainted with economics. That serious newspaper reader probably associates Federal spending with increased output (GNP) and employment, and prob-

Reproduced from Hack, David Bruce. Space program benefits. In Congressional Research Service. United States Civilian Space Programs: 1958-1978; report prepared for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives. Volume 1. Washington, For sale by the Supt. of Docs., G.P.O. 1983. p. 975-999.

ably associates these in turn with thoughts of higher rates of price increase, and perhaps also with higher money interest rates.

The loose association between aggregate demand and price increases (including interest rates) is a subject of intense and detailed study by economists. While all the details and mechanisms are certainly not agreed upon, almost all economists would agree that increased aggregate demand arising from Federal spending, somehow defined, is in at least a general and qualitative way associated with aggregate price increases. The specifics, and questions about the strength, of this relationship tend to become very complex, and are usually left out of news media accounts. NASA, which like all agencies must annually defend its budget requests before Congress, has been led to commission a detailed study of how the NASA R&D budget *specifically* affects national income and output (GNP), employment, and price increases (inflation). This study was done by Chase Econometrics Inc.[1]

In section 2 of the cited Chase study, the problem definition suggested above is sharpened considerably. Perhaps most importantly, the problem is defined as a forecast of short-run changes in output, employment and inflation arising from NASA R&D funding-rate changes of $1 billion annually, within a context of an unchanged total Federal budget. Chase shows that a very small and *beneficial* result, comes from a shift. The General Accounting Office, at congressional request, reviewed the entire Chase report.[2]

The GAO report dispensed quickly with the Keynesian-type short-run demand effect analysis of the Chase report, section 2:

> The results in section 2 are, in our judgment, reasonable estimates, in accord with widely accepted economic analysis. These effects are small, however, and they are not "benefits" in the strictest sense. Rather, they are measures of induced increases in the level of economic activity. As such, they are not crucial to deciding whether more or less money should be spent on NASA R&D, because similar effects could be obtained by other forms of Government spending—such as defense procurement or energy R&D. Tax cuts are, of course, a comparable alternative, although the size of their impact may differ. Because the results in section 2 are not particularly controversial or critical to budgetary decisions, we do not discuss them further in this report.[3]

In the Chase report "Conclusions," on page 34, Chase concludes as follows:

> In this section of the study, we have shown that a shift to NASA expenditures from other Federal Government spending will stimulate the economy without raising prices.

In view of the extremely small effects calculated by Chase, for a shift to NASA expenditures from other Government expenditures, the phrase "will stimulate the economy," though not qualitatively incorrect, may be quantitatively unimportant. Rather than suggesting that a good argument exists for making such a shift, the figures Chase presents suggest that budgetary shifts between NASA spending and general Federal spending should be made, if at all, on the basis of other and more important criteria, if such exist. On the other hand, the

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[1] The Economic Impact of NASA R&D Spending. (Prepared for the National Aeronautics and Space Administration under contract number NASW-2741 by Michael A. Evans) Chase Econometrics Associates, Inc. Bala Cynwyd, Pennsylvania. April, 1976. 121 pp.

[2] U.S. General Accounting Office. NASA Report May Overstate the Economic Benefits of Research and Development Spending. Washington, Oct. 18, 1977. 26 pp.

[3] Ibid., p. 3.

figures presented by Chase are even-handed in the following important way: taken at face value they imply that the burden of proof for those wishing to shift expenditures away from NASA toward general expenditures, and for those wishing to do the reverse, is about equal. In neither case can a good argument be made on the basis of short-run general economic effects.

C. Supply Effects—Research on the Aggregate GNP Supply Effect of NASA Expenditures

The Chase report goes on, in section 3, to analyze the more long-run effects on aggregate GNP resulting from changes in the aggregate supply, or the aggregate productive capacity of the economy, as a result of NASA R&D expenditure. An earlier analysis, having some similarity to the long-run analysis by Chase in section 3, was done by Midwest Research Institute.[4] The General Accounting Office report commented on the Chase study alone.

In the Digest of the GAO report, the GAO commented on the Chase report as a whole, drawing a distinction between the short-run demand analysis in section 2 and the long-run supply analysis in section 3. The General Accounting Office evaluated the Chase study as a whole as follows (excerpting here from the Digest of the GAO report).

> The Chase study does not prove convincingly that the benefits are as large as stated. The study is useful as exploratory research, but other types of studies are necessary to provide a complete evaluation of NASA research and development.
>
> The most significant conclusion of the Chase study is that "* * * a $1 billion sustained increase in NASA R&D spending will raise real GNP $23 billion by 1984 * * *." Of this estimated increase, $21 billion would result from improved technology and productivity, and the rest would result from increased Government spending, which stimulates spending in different parts of the economy.
>
> Since similar increases would result from Government spending on other projects, such as welfare programs, the "multiplier effects" [the "short-run demand effects"] alone do not justify more NASA research and development spending. For this reason, GAO focused on projected technological improvements.
>
> The Chase conclusions are questionable from three points of view:
>
> The results, even if accepted as accurate, do not provide the type of information needed to determine whether NASA's spending should increase or decrease. The estimates are of average, rather than incremental effects. Therefore they do not show whether more spending for research and development would result in as many benefits as before. Within NASA's budget, the most productive or unproductive projects or types of spending have not been spelled out.
>
> Even if the Chase approach is accepted, the techniques used had certain shortcomings. Plausible and seemingly minor changes in the study's assumptions lead to major changes in the results. Under some of these alternatives, NASA research and development seemed to have no great effect on productivity. Such sensitivity to small changes in methodology indicates considerable uncertainty in Chase's results.
>
> Basically, the results depend upon statistical correlation between NASA research and development spending and changes in a measure of gross productivity in the U.S. economy. No information on specific NASA projects or on the adoption of new techniques by private business is used in the study. Because of problems in measuring total productivity in the economy and because other

[4] Economic Impact of Stimulated Technological Activity. (Prepared for the National Aeronautics and Space Administration by Midwest Research Institute under Contract NASW-2030, Final Report.) Oct. 15, 1971. Summary Volume, 46 pp. Part I, "Overall Economic Impact of Technological Progress: Its Measurement," 61 pp. and appendixes; Part II, "Technological Progress and Commercialization of Communications Satellites," 130 pp.; Part III, "Knowledge Additions and Earth Links from Space Crew Systems," 81 pp.; and "Bibliography," 81 pp.

possible causes of technological progress were ignored, the correlations may not indicate a true cause-and-effect relationship.

Although the methodology of the particular study may be questioned, the importance of evaluating NASA's programs is undiminished. NASA has clearly been an important source of technical progress in recent years.

Section 3 of the Chase study, and part 1 of the earlier Midwest Research Institute study, both tackle a very similar problem. Both use somewhat similar economic theories.

Both Chase and Midwest Research Institute (MRI) base these portions of their studies on what economists call a production function. A production function is a mathematical equation which relates economic output, or the rate of change of economic output, to the levels or the rates of change of factor inputs such as labor and capital—and, in addition, to a variable representing technology, or the rate at which the available technology level changes. Both Chase and MRI use a production function to estimate economic gains or the increases in gross national product which arise from changes in the level of technology used. Changes in output which cannot be attributed to changes in the amounts of labor and capital available are attributed to the changes in the technology level, and this amount of otherwise-unattributed output change is referred to as a residual. Then, statistical techniques are used to estimate which of several plausible causes of the residual (that is variables which on theoretical grounds might cause gains in technology) are in fact responsible for the gains. Among the causal variables tested by either Chase or MRI is the expenditure on research and development made over the period by NASA (Chase) or by the total U.S. economy (MRI). Other variables are: the education level of the work force, and the age mix and the sex mix of the work force.

Both Chase and MRI recognize that most of the causes of technology change do not act all at once, but that technology changes occur only over a large number of years following a given R&D expenditure, or other cause. Chase bases its estimates of the lengths of these lags in part on the "17th Annual McGraw-Hill Survey of Business Plans for New Plants and Equipment."[5] Chase and MRI compute substantially different lengths of lag for the relationship between R&D expenditures and the GNP supply gained as a consequence of those expenditures.

In the MRI study, gains from research and development are spread over an 18-year period following the time of the particular R&D expenditure—although most of the gains are achieved by the end of about 12 years. Chase, on the other hand, estimates that the benefits in GNP supply begin to be seen in the fifth year, and increase each year to the tenth year following a given R&D expenditure. Thereafter, Chase treats the benefits as accumulating indefinitely at a constant rate. MRI based its estimates of the lengths-of-lags in part on "The Annual McGraw-Hill Research and Development Survey."[6] A discounted rate of return arising from the stream of additional GNP as a consequence of research and development expenditures, is estimated by both Chase and MRI. MRI estimates a discounted rate of return to R&D expenditures of 33 percent, as a consequence of a discounted 18-

[5] Chase. Op. cit., p. 81.
[6] Midwest Research Institute. Op. cit., Part I, p. 41.

year stream of benefits. Chase presents various equation estimates which fall within the range of 20 to 43 percent discounted rate of return, as a consequence of a discounted indefinite stream of benefits. Although the two study results fall approximately within the same range, they should not be regarded as fully conclusive, for reasons among which are those offered by the GAO in its review of the Chase study.

The GAO noted that under some equation forms it was not possible to determine that the returns to R&D expenditures were in fact statistically significant, and therefore some doubt remains about whether the Chase results (and the MRI results) are fully reliable.

The point at issue here is how much of the residual gain in GNP supply arises from NASA R&D, from other R&D, or from other effects which would take place in the absence of R&D expenditures of any kind—such as changes in the educational level, the age mix or the sex mix of the work force. The care with which these variables are chosen, and the exact form in which they are entered in the equation and tested, may make a very substantial difference in both the magnitude of the gains seen to arise from each particular variable, and in the extent to which the estimates of those gains may be regarded as statistically conclusive. MRI estimated that each dollar spent on R&D in general returns slightly over seven dollars in technologically induced economic gains over an 18-year period following the expenditure. Then MRI assumed that the gains over a similar 18-year period, from each dollar spent on R&D by NASA, would have a similar return; that is, seven dollars gained for one dollar expended. However, MRI indicated that:

> There is strong preliminary evidence that the exacting demands of the space program may produce greater than average economic effects due to increased technological leverage. This comes about because NASA allocates its R&D dollar to the more technologically intensive segments of the industrial sector of the economy. The weighted average technological index . . . of the industries which perform research for NASA is 2.1, while the multiplier for all manufacturing is 1.4. Although there are a number of conceptual and procedural limitations to the construction of industry-level technological multipliers, the spread seems large enough to support the view that highly technological undertakings, such as the space program, do exert disproportionate weight toward increased national productivity.[1]

Thus MRI claims that allocation of NASA expenditures to the more technologically advanced industrial sectors means that there may be greater than average returns from the NASA expenditures on R&D. This argument seems to go against the widely applicable economic result that the marginal returns to a single factor of production decrease when that factor is used in increasingly large proportion to other factors of production. Since MRI has chosen to regard technology as a factor of production, one might be led to the opposite conclusion. That is, insofar as NASA R&D increases the technology level of industries whose technology level is already high, the returns to increases in the technology "factor" might in these industries be lower than the returns to the technology factor in the aggregate economy. This matter could use further clarification.

The Chase study indicates that for each dollar expended on research and development by NASA the economy gains productivity begin-

[1] Midwest Research Institute. Op. cit. Summary Volume. p. 10.

ning in the fifth year, such that in the tenth year after the expenditure, and every year thereafter, 4.26 dollars of production are gained. Chase computes that this stream of benefits is equivalent to a 43 percent real rate of return. The difference in distribution over time of the Chase and the MRI streams of estimated benefits affects the extent to which the benefits are discounted. This may account for the similarity in the discounted rate of return estimated by MRI to that estimated by Chase, even though the total returns and the length of time over which the returns are distributed, are substantially different.

The short-run impact of shifting Federal expenditures by one billion dollars to NASA R&D from all other Government expenditures has been computed in the Chase study and has been found to be about nil. In the long-run productivity analysis, MRI performs no analogous calculation for NASA R&D compared to other Government R&D but instead assumes the effect of both NASA R&D and other Government R&D to be equal to that of all R&D, public and private. Neither Chase nor MRI performed any calculation to estimate differences between the returns to NASA R&D and the returns to other Government R&D. The calculation performed by Chase showed only that the short-run impact of shifting Federal expenditures between NASA R&D and all other Government expenditures is practically zero. It did not show what the result would be if the long-run returns to NASA R&D were compared with alternate expenditures for other Government R&D, such as Department of Defense R&D, or Energy R&D.

D. Case Studies of the Benefits of NASA-Developed Technologies

The MRI report goes on in part II and in part III to examine case studies. That is, to supplement the aggregate productivity analysis of part I, MRI examines in part II, "Technological Progress and Commercialization of Communications Satellites," and in part III, "Knowledge Additions and Earth Links from Space Crew Systems." The General Accounting Office, in its review of the Chase study, made the following recommendation to the administrator of NASA.

> Future evaluation studies should look at specific innovations, their effect on specific industries, and the process by which NASA expenditures for research and development improve productivity in the economy. In other words, some of the more important innovations, rather than the total budget, could be examined, and individual technological improvements in individual industries, rather than gross national product figures, could be studied. GAO believes that such studies would give the Congress a more accurate picture of what taxpayers are getting for their money.[8]

It is probably useful, GAO declares, to do micro studies as well as macro studies. That is, it is probably useful to examine some of the more important innovations and individual technological improvements in individual industries as well as to examine the impact of the total NASA R&D budget on gross national product figures alone. This

[8] General Accounting Office. Op. cit., p. iii. At the time of this writing, it is known that NASA initiated, in October 1978, a study by the Bureau of Labor Statistics, U.S. Department of Labor, as a response to this specific critique by the GAO. The study is expected to be conducted over about a two-year period.

does not mean that the GAO report must be read as concluding that further work should not be initiated and completed on aggregate productivity studies. As MRI suggested in its report, aggregate productivity studies and case studies of individual technological improvements arising from individual NASA programs may complement and perhaps reinforce one another. The first MRI case study is described next.

1. Commercialization of Communications Satellites (Midwest Research Institute)

In introducing its first case study in part II of its report, MRI commented as follows.

> [T]he technology application process, by which the economic effects measured in part I come about, almost defies an organized, comprehensive treatment. But some appreciation of the application process and its complexity is necessary if we are to insure a continuing flow of economic benefits from technological progress and avoid the widely discussed penalties of such progress. Faced with this situation the present researchers chose to undertake a case study of a significant technological endeavor, the intent being to illustrate—with specific examples—significant facets of the process, something of its pervasiveness, the kinds of contributions a national R&D agency, like NASA, makes to the process, and the several types of economic applications which flow from or are accelerated by such a technological undertaking.
>
> Since communication via satellite is clearly an example of technological progress made during the last decade and a half, an examination of the R&D effort culminating in this commercial application was selected for case study. In addition, communication via satellite is the first major direct commercialization of technology to result from the national space program.
>
> Part II had two segments: the first being an examination of the technological requirements which had to be satisfied before the several types of communication by satellite could be achieved, an examination of the national R&D program which has and is leading to the satisfaction of the requirements, and the technical contributions of and roles played by NASA in this R&D process; the second being an examination of ways in which participants (NASA contractors) in the NASA portion of the R&D effort . . . have applied the technological capabilities they acquired or augmented during the R&D phase in the resulting *commercial* communication by satellite market and other markets.[9]

a. *Study Plan.*—The MRI report indicates that the major research steps undertaken in connection with satellite communication were to examine the several categories of services which could be provided by communication satellites, and to group these services into four broad types for subsequent investigation. The types selected were: *International*, such as Intelsat/Comsat; *Broadcast Distribution*, such as transmission via satellite to major centers with transmission to ultimate users via conventional terrestrial links; *Direct*, such as transmission to many users direct from the satellite; and *Mobile*, communication via satellite with mobile users, such as in air traffic control. MRI then indicates that the research procedure followed in this case study was to delineate the major technical characteristics or requirements associated with each of the four types of applications.

MRI examined the contributions which NASA programs—particularly SYNCOM and ATS—have made to the satisfaction of the requirements. Then MRI estimated the economic impact associated with the four types of applications. Finally MRI identified and interviewed

[9] Midwest Research Institute, Op. cit. Summary Volume. pp. 12–13.

a representative set of contractors that participated in the SYNCOM and ATS programs to identify the extent and ways in which they participated in the commercialization of satellite communications, and in the indirect application of the technological capabilities they accumulated during their participation in this facet of the space program.

MRI indicates that at least 277 firms participated as prime contractors in the communications aspect of NASA's SYNCOM and ATS programs. MRI selected 14 of these following an intensive sample selection process. This was done because of the need to obtain as representative a cross section of participating companies as possible—that is, large and small firms, satellite and ground stations contractors, aggressive and not so aggressive firms, and so on. Two additional firms which were not prime NASA contractors were added to the sample. One was a direct spin-off from one of the prime contractors. The other was a newly formed company that utilized satellite communications technology in a rather unusual way to assemble and market a marine navigational system.

b. *Commercial Achievements.*—The first satellite commercialization was in the *international* system, which came in the form of the INTELSAT Consortium of which the Comsat corporation is the U.S. partner. Service began in 1965, and when the MRI report was published in 1971, plans called for service to almost 60 nations by 1974.[10] The MRI case study on commercialization of communications satellites indicates that the first domestic *broadcast distribution* system was to be the Canadian Telesat system scheduled for operation in 1973.[11] In the United States, eight applications to provide various mixes of domestic service were pending before the Federal Communications Commission by 1971. There were no commercial plans as yet for direct domestic systems in 1971, although a demonstration experiment for such a system in India was then planned for 1974.[12] The first all-commercial system of the *mobile* type was planned to be in air traffic control and navigation. A prototype system for trans-Atlantic flights was planned for 1975, with service over the Pacific to follow a year later.[13] The MRI case study continues by summarizing the technological history of communications satellites research and development, placing particular emphasis on the following projects: the ECHO Project—a passive communications satellite, TELESTAR and RELAY—medium altitude active repeater satellites, and the ADVENT, SYNCOM and ATS programs—synchronous communications satellites.

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[10] By 1979 this system had grown to serve 102 nations.

[11] Canada was the first country to establish a domestic communications system with geostationary spacecraft. The Telesat Corporation, acting for Canadian telephone and television systems, launched three Anik satellites—in 1972, 1973 and 1975. Telesat constructed a network of 50 ground stations and developed an annual operating revenue of $28 million. Service is provided at prices competitive with a well established microwave network, and "uniquely throughout the Far North." Space, A Resource for Earth. New York, American Institute of Aeronautics and Astronautics. April 1977. 67 p. (p. 7)

See also: U.S. Congress. House. Committee on Science and Technology. World-Wide Space Activities [Report prepared for the Subcommittee on Space Science and Applications by the Science Policy Research Division, Congressional Research Service, Library of Congress], 95th Congress, first session. Washington, U.S. Govt. Print. Off. September 1977. 607 p. ("Canada," p. 107–109).

[12] The Satellite Instructional Television Experiment (SITE), a joint program involving the United States and India, was conducted from mid-1975 to mid-1976. U.S. Congress. Op. cit., p. 120–121.

[13] This system (AEROSAT) was later cancelled, after publication of the MRI report. Neither the Atlantic nor the Pacific has an air traffic control satellite communications system as of 1979.

The purpose of the MRI historical review was to illuminate some of the key technical developments that led, cumulatively, to our present knowledge and capability in the communications satellite field. The review demonstrated that practical progress has occurred across a broad technological front. This was illustrated by the fact that by 1971 a commercial communication satellite system had been in operation for six years, while only slightly more than ten years prior to 1971 many experts had serious doubt that satellites could be placed in synchronous orbit before 1970, that satellities could survive in space and operate long enough to be economically viable, that the quality of satellite communications transmission would be acceptable, and that the cost of satellite systems would be competitive with traditional earth-based communications.

c. *Further Technical Benefits.*—The MRI case study goes on to say that the public often fails to grasp the multiplicity of roles which Government R. & D. agencies play in the technological progress processes. MRI indicates that only in instances where the complete NASA-developed systems are commercially applied as a whole package, is the link to the space program readily apparent. Such clear-cut transfers do occasionally occur, said the MRI case study. For example, MRI cited NASA SYNCOM III, saying that it became the commercial INTELSAT I, but MRI indicated that such direct commercializations of an entire system are rare. More subtle relationships are more often the rule. Less obvious roles played by NASA in the development and commercial applications of technology, as cited by MRI, include the following:

Conducting In-House Research.—MRI gives, as an example of NASA in-house research contributing to commercial applications, the mechanically despun antenna used in INTELSAT. The initial idea came from Kampinsky's laboratory group at Goddard Space Flight Center. Subsequently, Sylvania laboratories did the actual design and fabrication with key assistance from Ball Brothers, Kearfott, and Mechanical Technology, Inc. Antenna performance was validated on ATS III and after additional work Intelsat incorporated the mechanically despun antenna in its third generation of satellites.

Generation of New Knowledge and Understanding.—MRI indicated that this is achieved by the performance of scientific experiments which provide the basis for technological improvements. The findings of the Earth's triaxiality and the mapping and location of "graviation grave yards" underlay the selection of positions for geostationary satellites so that they might be maintained on station much longer than their station keeping expendable supplies would otherwise permit.

Classic Request for Proposal Process.—MRI indicated that in this process application requirements are defined, technical planning is undertaken, and these needs are made known in research organizations and the industrial community through the procurement process. This is a traditional and well established way of motivating innovations which often advance the state of the art.

Initial User or Initial Adopter.—MRI indicates that: given knowledge of NASA mission and technical requirements, aggressive firms often undertake developments in anticipation of marketing the results to NASA. Cassegrain feed systems, for example, received early impetus

via this role and are now the standard approach for large ground stations. Suppliers now enjoy the Intelsat market.

Alternative Evaluation.—There are almost always alternative technical paths, MRI indicated, by which a requirement can be satisfied. NASA in its role as an R&D agency has provided the wherewithal for exploring the competitive advantages of alternatives. Tests of cryogenic masers versus cooled parametric amplifiers are a case in point.

Demonstration to Acquire Confidence.—MRI indicated that an important aspect of technological progress is the reduction of uncertainty. NASA flight programs have made many contributions of this type through the accumulation of operating confidence and predictability.

d. *Selected Commercial Investment Figures.*—MRI provided indicators of the present and future economic impact of the development of communications satellite technology and its application in the commercial sphere. For example, MRI compared early estimates of the cost of communications by satellite with the dramatic cost declines actually experienced as the technology evolved. MRI noted that the reductions in cost are striking and that similar cost declines have been experienced in Earth station costs. MRI noted that because satellite communication offers both service advantages and cost advantages over preexisting means of communication, growth in the international application has been dramatic, and MRI provided examples. MRI indicated that in spite of the rapid growth of the *international* application, the economic impact of domestic *broadcast distribution* would be much greater. The total overseas telephone and telegraph traffic, MRI indicated, was on the order of 50 million messages per year, while over 8 billion domestic long-distance messages are carried annually.

MRI indicated that in 1971 a total of eight applications for domestic satellite networks were pending before the Federal Communications Commission. The proposed initial investment ranged from about 100 million dollars to over one-quarter billion dollars. MRI noted that several of the applicants had pledged to have their systems in full operation in less than three years after FCC approval.

In Canada, a $90 million domestic system was planned to be in full operation by mid-1973. The bulk of the equipment was to be supplied by U.S. firms.[14]

MRI said that the first commercial *mobile* application would be an aeronautical satellite system providing communication links for transoceanic airline flights. Expectations as of 1971 were for an investment in the $125 million to $150 million range for a two-ocean system by 1977.[15]

e. *Indirect Economic Impact.*—The MRI case study on commercialized satellite communications indicated that most of the firms that performed substantial technical work in developing or experimenting with the NASA communications satellite systems were themselves affected in a variety of ways—some organizations to a greater extent than others. MRI made the following flat statement in summarizing the indirect economic impact on aerospace contractors:

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[14] The $90 million figure appears to be an investment estimate. Annual revenues had risen to $28 million by 1977. American Institute of Aeronautics and Astronautics. Op. cit., p. 7.

[15] These investments were cancelled. There is no satellite system providing communication links for transoceanic airline flights, as of 1979.

Conceivably the most significant finding from the study of these contractors is simply that *every firm interviewed* indicated that their performance of space communications work had produced some residual economic effect. Not all effects were easily identifiable, but the challenge of high technology and the response by the company was stated to have influenced the firm or "left its characteristic mark." [16]

MRI said that the lasting consequences identified fell broadly into three classes or types of influences. First there were internal effects on the firms. Some firms modified their processes and procedures, the internal structure of the division, the way they operated, their management systems, tighter quality control; or perhaps introduced new procurement policies or more efficient production methods. "Economic effects from these internal changes are usually known as efficiency or increased productivity," according to the MRI case study.

Second, in addition to the internal effects, the majority of firms studied found ways to utilize the knowledge, expertise, and product capabilities that were augmented through NASA satellite work to establish or to strengthen their position in supplying the needs of commercial satellite systems. However, according to MRI, much more was involved than a simple decision to sell satellite systems to another customer.

Procedural as well as technological changes are also required as part of the changeover effort needed to sell to new markets or to commercial users having non-NASA requirements. But all contractors interviewed felt that the economic rewards derived from switching over to commercial sales were worth the efforts.

The third effect on NASA contractors was that some firms utilized new knowledge, experience, and heightened perception of changing market needs, to transfer emerging or developed skills into new non-space markets. New ventures, new services, non-governmental markets needing similar skills, and most of what has traditionally been called "spin-off" was found in this category of company effects. The economic effects are hardest to trace here. Seldom was there a direct one-to-one transfer; more commonly the transfer was feasible only because the contractor suddenly perceived that a need, a technology and a market were approaching conjunction.

MRI stated that technological change does not occur spontaneously people have to make it happen. The "internalized costs" of innovation are not trivial. These costs include (1) the cost of acquiring new knowledge—about market needs, about external situations, and about the availability of new technology; (2) the cost of learning to apply this new knowledge to the satisfaction of economic wants—education and training of production and marketing personnel, feasibility demonstrations and trial marketing; (3) the "changeover" costs (obsolescence and sunk costs) of abandoning old ways and adopting new ways of performing the firm's economic function.

MRI said that recent scholarly studies of innovation had unmistakably shown that the force that induces industrial innovation is the economic pull of the marketplace, not primarily the forward thrust of new technology.[17] The costs and barriers that impede the adoption

[16] Midwest Research Institute. Op. cit. Summary Volume, p. 26. Emphasis in the original.
[17] Midwest Research Institute. Op. cit. Summary Volume. p. 27. Part I, p. 122. See also Bibliography, pp. 12–31.

of new technology (such as those cited above), are never easy to surmount. Within large organizations possessing considerable inertia, powerful forces are necessary for the successful introduction of any innovation.

MRI summarized the case study of commercialization of communications satellites in the following words:

> Yet the fact is that innovation does occur, regularly—in both large and small companies. Firms do learn, adopt new techniques, improve designs and enter new markets—because technical change and innovation offers handsome economic benefits. A number of specific examples of this economic force at work were found during the survey of sample contractors.[18]

MRI illustrated the above statement by providing an extensive list of individual companies which had reported to MRI on benefits which those companies had experienced.[19]

2. Technical Change Effects of Environmental Satellites (NOAA)

The section just above discussed the technological progress arising from commercialization of communications satellites. This is a primary application of NASA-developed technology. The second case study also involves a primary application of NASA-developed technology. The second case study presented in this section is a summary of the economic benefits of environmental satellites. The documentary source of this case study was published by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.[20]

NOAA environmental satellites are used on a continuous basis to monitor the weather and weather-related phenomena around the world, especially in the western hemisphere. The technology for this Commerce Department program was developed, and its feasibility demonstrated, by NASA. The NOAA document cited indicates that two prototype satellites were launched by NASA on May 17, 1974 and February 6, 1975. Two NOAA-funded satellites were launched October 16, 1975 and June 16, 1977. All of these four satellites were operational in 1978; two were being used regularly and two others were in orbit on standby duty. Each of these four satellites is a geostationary satellite—meaning that it circles the Earth once each twenty-four hours and thereby remains in a fixed location over the Earth's surface. NASA has also developed, and NOAA is using, polar orbiting satellites which sweep around the Earth from South Pole to North Pole as the Earth rotates beneath the orbit. In 1978 the operational NOAA polar orbiting satellite was NOAA–5, which was launched in 1976. This satellite and others in its series were scheduled to be phased out in 1978, in this rapidly developing technology, and replaced by a new third-generation series of operational polar orbiting satellites.[21] In the following section the technological benefits which the spacecraft of the National Environmental Satellite Service have brought to industrial and commercial activities and to operations of the Government are discussed.

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[18] Midwest Research Institute. Op. cit. Summary Volume. p. 27.
[19] Ibid. pp. 29–33. Also op. cit., Part II, pp. 82–125.
[20] U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Environmental Satellite Service. The Economic Benefits of Environmental Satellites (by W. John Hussey and E. Larry Heacock). April 1978. 33 pp. Presented at the Fourth Annual Convention of the Eastern Economic Association on April 27, 1978, Washington, D.C.
[21] NOAA–5 is still in operation (May 1979). The first TIROS N prototype (successor to the NOAA series) was launched in 1978. The TIROS system is still experimental.

a. *Some Estimated Dollar Benefits.* Satellite data have assisted ships at sea to save fuel by plotting navigational courses to take advantage of ocean currents. They have helped the Florida citrus industry save fuel, which would otherwise be used to heat Florida citrus groves on cold winter nights. Satellite weather data have helped the Hawaiian sugar cane industry plan its harvest, and avoid crop losses due to unforeseen weather conditions. Satellite weather data have helped to pinpoint the location of rough weather conditions where general aviation aircraft have been lost. As a consequence a substantially reduced amount of flying time is required to locate lost aircraft, with consequent fuel and other savings. Satellite weather data have helped to extend the shipping season in the Arctic Ocean and the Great Lakes. Satellite weather data have helped farmers plan agricultural operations which are weather-dependent. NOAA satellites are able to map snow cover over land areas, and to predict flooding from prospective snow-melt conditions. Satellite-based infrared imagery can depict the location of thermal boundaries or "fronts" on the ocean surface. It is known that certain species of fish such as blue fin tuna and salmon tend to congregate in temperature-specific regions of the ocean, and these temperature-specific regions of the ocean can be located through satellite infrared imagery. This has helped the fishing industry use less fuel while at sea, as well as to increase the catch. NOAA satellites provide environmental data to forecasters and Government officials regarding tornadoes, severe thunderstorms, hurricanes, tropical storms, flooding, severe winter storms, and other less destructive environmental phenomena. Satellite data are transmitted 24 hours per day, 7 days per week to the various national centers for environmental warning. Satellite imagery is used extensively in monitoring tropical storms and hurricanes.

The cited NOAA document states the following:

> Since the inauguration of the operational satellite system, no tropical storm goes undetected, even in the most remote areas of the world. Hurricane reconnaissance aircraft no longer have to fly random search patterns over the tropical oceans to locate storms which may be brewing there. Estimated savings for using satellite storm detection and monitoring in mid-ocean in place of expensive aircraft reconnaissance are about $1.8 million annually.
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> A 1975 NOAA Technical Memorandum . . . noted that until 1974, the initial position error for storms within 500 [nautical] miles of the coast averaged 22 [nautical] miles, and landfall forecasts were made from distances no more than 300 [nautical] miles. A positioning error is defined as the difference between the forecaster's assumed initial position of a storm and the actual position as determined from a post-analysis.
>
> The issuance of hurricane warnings along a portion of the United States coast line is generally accomplished 18 to 24 hours prior to the expected arrival of the storm at the coast. This particular time interval has been found to be an optimized trade-off between the desire to provide maximum warning lead time and the ability to keep the size of the warning area within reasonable limits. With such a lead time, the length of the warning zone averages nearly 300 [nautical] miles. Inasmuch as the swath of damaging winds is generally less than 100 [nautical] miles, the public must expect a minimum overwarning area of about 200 [nautical] miles.
>
> A 20% increase in the size of a hurricane warning zone can be expected if the currently observed positioning errors are increased an average of 10 [nautical] miles. However, a 10 [nautical] mile decrease in positioning area yields only an 11% decrease in the size of the warning area.
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> • • • • • • •

It is estimated that protection costs (including losses due to temporarily curtailed production) for a typical 300 [nautical] mile Gulf of Mexico coastal hurricane warning zone total $25.1 million. A 10 [nautical] mile increase in positioning error will thus increase this economic loss by about $5 million per storm. A 10 [nautical] mile decrease in positioning error will decrease protection costs by about $2.75 million per storm.

Since an average of about two hurricanes annually move inland on the continental United States, using the above figures, $50.2 million is the average annual cost of protection. As a conservative estimate, a reduction of only 5% in the coastal warning area would mean an average annual savings of about $2.5 million per year. Satellites play a major role in keeping the warning area to a minimum.[23]

b. Unquantifiable Benefits.—In addition to the nine areas named above, in which the National Environmental Satellite Service satellites provide economic benefits which are both tangible and measurable, these satellites also contribute heavily to the National Weather Service's National Meteorological Center, the central weather analysis and prediction facility for the United States. In a 24 hour period, the National Meteorological Center receives about 42,000 conventional weather observations, plus a large volume of satellite observations. The National Meteorological Center synthesizes all types of meteorological data such as satellite, surface, upper air, and radar observations. This results in a more complete and accurate understanding of atmospheric processes.

NOAA, in the 1978 report cited, summarized as follows:

The environmental satellite is an excellent global observational platform and the United States freely contributes data from its satellite to the world meteorological community. Satellite data is an important part of the World Weather Watch Program of the United Nation's World Meteorological Organization. The direct readout systems . . . from the polar orbiting spacecraft and the . . . transmissions from the geostationary spacecraft are extremely useful in as many as 120 countries around the world. A large international project called the Global Atmospheric Research Program is underway in which satellites play a primary role in gathering atmospheric data on a global scale.[24]

Thus, environmental satellites contribute significantly to large scale or global weather observation and forecasting, but it is impossible to derive an actual cost benefit in annual dollars saved. To obtain the quantity and coverage of data which the satellites provide by more conventional observation methods such as surface observations, radiosonde, radar, meteorological buoys, etc. would not only be prohibitive from the cost standpoint, but it would be essentially physically impossible. The value of satellite input to global scale observations is certainly in the many millions of dollars.[25]

c. Environmental Satellite Benefits Summarized.—The National Environmental Satellite Service summarized the estimated annual savings from the nine categories discussed above in which annual savings estimates were possible. The fuel savings in Gulf Stream navigation arising from helping ships steer into currents going their way, and steer away from currents going against them, is estimated to be $360,000 annually by the EXXON Corporation alone. The Florida citrus industry is estimated to save $48,000,000 annually, assuming an average year in which there are 35 "cold" nights per year—that is, nights in which heating of groves is required. In the Hawaiian sugar cane industry the estimated annual savings of crop losses is $1,000,000 for

[23] U.S. Department of Commerce. Op. cit. pp. 20–22.
[24] The Global Atmospheric Research Program (GARP) has been continued, and will be continued at least through Dec. 31, 1979.
[25] Ibid., p. 27.

the Waialua Sugar Company only. In search and rescue, it is estimated that $7,300,000 are saved due to reduced flying time by the United States Air Force Aerospace Rescue and Recovery Service, and the California Wing of the Civil Air Patrol, because pinpointed weather conditions permit downed aircraft to be located in a matter of about 48 hours instead of approximately a week. It is estimated that the Arctic and Great Lakes ice monitoring saves $35,000,000 by extending the shipping season on the Great Lakes 30 days annually. The General Agriculture Industry is estimated to save $74,000,000 annually, as a consequence of satellite weather data. The snow cover mapping capability of NOAA satellites is estimated to save about $100,000 in flying time for snow cover mapping of the Sierra-Nevada Basin alone. In the West Coast fishing industry it is estimated that the savings in fuel by ships at sea while locating schools of fish, plus the value of the increased catch of fish, is $2,440,000 annually, for the albacore and salmon fishing industries only. For disaster warnings, it is estimated that $4,300,000 worth of economic production is saved annually due to improved hurricane warnings only. Finally, in large-scale weather forecasting, NOAA regards it as impossible to estimate a dollar savings. The dollar savings here is regarded as unknown but considerable. The total estimated annual savings for the nine categories in which estimates have been made is $172,500,000. The National Environmental Satellite Service document from which these figures are taken indicates that the total National Environmental Satellite Service budget for FY 1978 was $94,300,000, or about half the cost savings arising from these few selected areas.

3. Secondary Effects—Gross Technical Change Effects By Industry (Mathematica)

The first set of case studies of secondary effects of NASA-generated technology have been described by Mathematica, Incorporated, under NASA contract.[25]

Mathematica stated that the most widely accepted principle for evaluating economic benefits is founded on individual "willingness to pay" to move from a "less" to a "more" preferred state.[26] Mathematica says that what this principle translates into for the purposes here is that the benefits of technological change can be measured as the cost savings generated by new or improved production processes, plus the extra value that consumers attach to new or improved final products. (An economist might describe this as being the sum of the changes in the producer profits and the consumers' surplus as a result of technological change.) Mathematica says that by determining how cost and demand for various products are affected by specific technological advances, one can estimate the benefits of these advances.

Further describing its methods, Mathematica indicates that the research process by which technological advantages are generated typically involves a complex interaction of various groups and individuals. In solving the particular problems associated with an advance, the

[25] Quantifying the Benefits to the National Economy from Secondary Applications of NASA Technology. (Prepared for the National Aeronautics and Space Administration by Mathematica, Incorporated), Princeton, N.J., June 30, 1975. 176 pp. Executive Summary. 10 pp.

[26] Mathematica. Op. cit. Executive Summary. p. 3.

individual research "actors" build up or combine their results with those generated by others. The "credit" for the benefits created by a particular advance should, in a real sense, be shared by the various contributors.

But it would be helpful to be able to assign a particular share in some specific cases. The method used by Mathematica for assigning the share is based on the premise that NASA R&D led to an earlier realization of the particular technological advances being considered. According to Mathematica, this view of technological advance has been proposed and defended by a number of authors.[27] This view specifically is that had NASA not done its R&D, these technological advances would still have occurred, but at a later date. As a consequence of this, the measurement of benefits attributable to NASA becomes in principle a rather straightforward task. Mathematica concludes that the benefits can be measured as the difference between the present value of two benefit streams: one, the stream resulting from the advance that has occurred, and two, the stream that would have resulted had NASA not been involved. Mathematica questioned technical experts outside the NASA establishment about the speed-up resulting from NASA's role. Of course, their judgements varied. In order to allow for this, the extent to which NASA accelerated the time stream of benefits was calculated based on a minimum, a maximum, and a conservative "probable" speed-up due to NASA. Mathematica did not select areas for study randomly, but deliberately selected cases on which data were available, where NASA's role was widely acknowledged, and where benefits were anticipated to be relatively large. "Consequently, until additional experience with more case studies is acquired, it is not possible to draw inferences regarding the total secondary benefits of NASA's R&D." [28]

Mathematica attempted estimates of secondary benefits from six NASA technological areas, and was able to complete four of these. The others were not completed due to data unavailability.

First, it was estimated that NASA research on jet propulsion had advanced the technology of gas turbine engines by approximately one year, and that this had caused a total cost savings in the electric power generating industry of approximately $111,000,000, as a consequence of higher energy-conversion efficiency.

Second, Mathematica estimated the economic benefits arising from multilayer cryogenic insulation, developed by NASA for use in handling liquefied gases. It was estimated on the basis of a survey of expert or informed opinion that NASA had advanced this technology by approximately five years, and that the benefits accruing to industry from the five-year speed-up of this technology were approximately $1,054,000,000.

Third, Mathematica further estimated that NASA R&D had speeded up the development of integrated circuits by about two years, and that the "probable" benefits arising from use of integrated circuits in all types of electronic products were approximately $5,080,000,000.

Finally, Mathematica estimated the benefits to producers and consumers of a large multipurpose computer program which was devel-

[27] Mathematica, op. cit., p. 17.
[28] Mathematica. Op. cit. Executive Summary. p. 5.

oped with NASA support. This computer program package is called NASTRAN, for *NA*SA *STR*uctural *AN*alysis. This computer software package was designed for static and dynamic analysis of the behavior of elastic structures. It is used principally by general product engineers in mechanical or civil engineering applications, including aircraft and automobile production, bridge construction, and power plant modeling. Estimates of cost savings from the use of NASTRAN were obtained from telephone interviews with a sample of users. From the sample responses "probable" benefits accruing to the population of NASTRAN users were estimated by Mathematica at $701,000,000.

The total of these four estimates of "probable" benefits arising from NASA-developed technology, or technology which NASA research helped to make available earlier, is $6,946,000,000. Mathematica concluded as follows:

- Operational methods can be developed for estimating the secondary benefits of mission oriented R&D.
- Secondary benefits attributable to NASA R&D programs may be impressively large. For example, the $7,000,000,000 total for the four cases studied is more than twice NASA's present yearly budget.
- Because secondary benefits may indeed be significant, public decisions concerning the allocation of resources to research and development programs should, where possible, consider such benefits.[29]

4. Secondary Effects—Earth Links of Space Crew Systems Development (MRI)

Case studies of the secondary effects of NASA-developed technologies are continued here by returning to the Midwest Research Institute report, part III. This case study examines the technological improvements, and suggests economic benefits, arising from the research, development and production of space crew systems—that is, those systems designed to support human life in space, and to enable space crew members to perform work in space. MRI titled this case study "Knowledge Additions and Earth Links from Space Crew Systems."

a. *Why Study Space Crew Systems?*—MRI asserts that the worldwide knowledge bank consists, in simplest terms, of everything known to man. It includes everything from knowledge on basic phenomena to manufacturing "know-how." As the problems addressed become more complex, additions and refinements to the knowledge bank are essential. MRI says that another characteristic of the knowledge bank is that the information in it usually contributes to the solution of problems beyond those visualized by the original developer. Thus, the ultimate utility of any piece of know-how cannot be assessed at the time of its generation.

The means by which the knowledge bank is added to and refined include both basic research, and the efforts of individual innovators faced with very specific problems. Somewhere in between these extremes is so-called mission-oriented research, of which the space program is an example. Since mission-oriented R&D programs typically stretch some aspect of the state of knowledge and ultimately culminate in hardware, they often make broad contributions to the knowledge bank—in the basic and applied sciences, in several engineering fields, in manufacturing processes, in analytical techniques, and so on.

[29] Mathematica. Op. Cit. Executive Summary. p. 10.

MRI stated that it chose to examine the contributions expected of mission oriented R&D by means of a case study of those aspects of the manned space program directly related to human life support and work performance in space. Much of the information needed to design life- and work-supporting systems was not available. Therefore, scientists had to undertake research. Physiologists and others had to become much more precise in their understanding of human life requirements. In many instances, the knowledge available to engineers in their own fields was inadequate for the task at hand—in much the same way that physiologists' knowledge of requirements was lacking. Research was supported to develop data and extend the available engineering knowledge. In many instances, new knowledge was necessary in the manufacturing and testing of the equipment also. New materials were required, tolerances were smaller, reliability had to be higher, and so on.

b. *Study Plan.*—MRI conducted this case study through personal interviews with NASA contractors and NASA laboratory personnel. Several participants in crew systems research and development at each firm or lab were asked:

- What did you have to learn in order to do your part of the manned space program, i.e., what was known and unknown when you began?
- What sort of solutions did you develop and apply?
- How, if any way, does what you learned or what you did relate to Earthly problems? [∞]

c. Nine Space Requirements Linked to Earthbound Issues.—MRI said that ten to twelve illustrations of new or improved knowledge were noted in each hour to hour and one half interview, and most of the knowledge gained had some relationship to needs here on Earth. In total, part III of the MRI report presents over 130 illustrations—indentified during the limited number of interviews—wherein knowledge additions were traceable to the crew systems efforts of the space program.

Part III is arranged in terms of nine requirements which had to be met to maintain man alive and productive in space. The nine requirements are the following: the supply of breathable atmosphere; carbon dioxide removal, and carbon dioxide recycling; contaminant control and removal; maintenance of thermal balance; space hazards—decompression, radiation, meteorites, fire and blast; provision of adequate light and vision; provision of mobility and work capability; provision of adequate habitability. MRI found that in total almost 200 links to down-to-Earth issues were identified. Though not all of the identified links may come to pass, other less obvious linkages may emerge. MRI noted that predicting areas of greatest utility for given pieces of new knowledge has been subject to significant oversights throughout history. Thus the linkages identified by MRI are those which seemed most clear to the authors. They were offered only as indications of ultimate impact.

NASA developed improved heat exchangers which could result on Earth in smaller, quieter heat pumps and air conditioners.

NASA developed heat pipes to transmit metabolic heat through the space suit and into space for temperature control. TRW Systems Division which developed the heat pipes for cooling space suits, has

[∞] Midwest Research Institute. Op. cit. Summary Volume. p. 36.

since granted licenses for the use of this technology for industrial process furnaces. A major use of these furnaces will be the production of semi-conductors, which require extremely uniform heat treatment. Other heat pipe applications range from the processing of jet aircraft turbine blades to cooling nuclear reactors.

NASA developed improved vacuum evaporators with which to purify water. This knowledge adds to the technological base underlying a number of commercial processes which remove water from heat-sensitive products such as instant food products, instant coffee and soups, and dry non-fat milk.

NASA developed a coordination tester to determine the effects of atmospheric contaminants on astronauts' performance. The device permits measurements of hand-eye coordination in several tracking and pursuit tasks, and the influence of toxic materials and fatigue can be determined. This device has been found to be suitable for testing automobile driver coordination and the effects on such coordination of air pollutants, carbon dioxide, carbon monoxide and alcohol.

NASA developed an optical grade polycarbonate sheet plastic for use in space suit helmet faceplates. Earth applications are for safety, riot control and motorcycle faceplates, aircraft windows or canopies, and screens around hockey rinks.

NASA developed an eye motion measurement instrument called an oculometer. The oculometer measures eye movement in carrying out search and discrimination tasks to determine the speed and efficiency with which the eyes process information within the visual field. Persons engaged in activities requiring vigilance and highly developed discrimination can be aided by training based on oculometer data. The oculometer provides real time eye movement tracings which are displayed on a screen. Thus an instructor can coach the pupil in improving eye use. The procedure provides the means of testing concentration and alertness. The oculometer has utility in training air traffic controllers and quality control inspectors, in reading analysis and psychological testing, and for "studying the earlier development of the oculcmeter system in children." [31]

NASA required the development of rubbers and plastics that would not burn in oxygen. The resulting elastomers have the capability for use in a variety of oxygen-rich environments. Anesthesia hoses and masks, interior decorative panels on commercial aircraft, and upholstery coatings in aircraft, are some of the uses of these elastomers.

NASA developed water electrolysis systems capable of furnishing crew oxygen for more than ten-thousand hours. The operation life of previous electrolysis units was typically limited to one-thousand hours. On Earth, at present, there are a number of situations which require that oxygen be stored at high pressure. This is an inherently hazardous procedure. The NASA-developed electrolysis system is being tested for military aircraft, and is under consideration to replace high-pressure oxygen for emergency use by commercial airline crews. The system provides oxygen on demand and does not require storage. Water electrolysis is also being investigated as a source of oxygen for newborn infants. To prevent eye damage the amount of oxygen supplied to the incubator or isolette must be precisely controlled. Present practice is to

[31] Midwest Research Institute. Op. cit. Summary Volume. p. 43.

measure flow rates of the oxygen being delivered from storage tanks. Greater precision can be obtained by water electrolysis generation of oxygen, because oxygen production is directly related to the supply of electrical current to the unit.

The final example which MRI offered in this case study of NASA-developed technology for the support of life in space, and having applications on Earth, was the development of direct whole-body calorimetry. As a consequence of NASA research and development, direct, whole-body calorimetry can now be performed conveniently and accurately on a real-time basis, by recording heat transmitted to liquid cooling garments. Previous techniques were indirect or restricted in the extent of human activity permitted, or had slow response rates which precluded study of thermal transients. On Earth, direct calorimetry is being employed on a number of research topics, including: physiological research on basic body homeothermic and metabolic processes; medical research on fever and antipyretic treatments, on diet—such as the specific dynamic actions of various classes of nutrients; on metabolic disorders—such as thyroid functions; on the various types of shock and the physiological processes involved; on heat exhaustion and sun stroke investigation; in industrial hygiene for the study of workers in hot and cold environments, for the establishment of work standards and practices; and even in the study of athletic stamina and endurance.

Midwest Research Institute concluded the case study of part III in the following words:

> The findings of this study indicate that the long term economic benefits of the space program are much more profound than superficial examinations would indicate, and that the importance of technological progress to national well-being must not be ignored. However, much remains to be learned about the specifics of how technology interacts with the economy. The investigations reported upon in this five volume work were performed within the current state of the art. There is a need to extend and refine our knowledge on many aspects of advancing technology and its economic and social impacts. The present researchers hope that this study will encourage others to seek better understanding of the processes involved and more precise answers to the questions we addressed.[88]

E. How the Case Studies Relate to the Aggregate GNP Supply Effects Analysis

This completes the survey of two broad categories of study, both directed to estimating the economic effects, or the increase in economic productivity, arising from innovation in general, and specifically from innovation promoted by NASA R&D expenditures. The first broad category of productivity analysis was the aggregate economic productivity analysis illustrated by both part I of the Midwest Research Institute study and by section 2 of the Chase Econometric Associates study. The second broad category of technology improvements analysis has been the case studies described just above.

The aggregate productivity analyses have the advantage that they cover the whole economy. They have the disadvantage that, for many readers, they cover the whole economy in a rather too-abstract way. They have the further disadvantage that the details of the methods employed are not entirely agreed upon by Midwest Research Institute and Chase Econometric Associates, nor for that matter are these

[88] Midwest Research Institute. Op. cit. Summary Volume p. 46.

methods fully developed by the economics profession at large. It is encouraging however that NASA, whose primary mission involves research and development in the physical and engineering sciences, has commissioned economic and statistical studies of the economic effects of its activities. These studies were apparently at or near the frontier of relevant economic analytic knowledge as that frontier was known when these studies were commissioned, and when they were completed in 1971 and 1976.

The case studies (in contrast to the aggregate productivity analyses) have the advantage that they lend concreteness to the analysis of technological and economic effects of NASA R&D expenditures. Conversely, they have the disadvantage that they are partial, local and not exhaustive of the full range of NASA benefits, and impacts on the economy at large. The case studies have the further advantage however that they serve to illustrate the processes at the technological level, the innovation level, and the industry level, which are assumed to add up to the aggregate technological improvement, and the aggregate economic benefits, which are estimated in aggregate productivity analysis. The case studies described so far are successful in that they do illustrate in a concrete and down-to-Earth way, some of the mechanisms which are presumed to underlie the aggregate economic estimates.

The General Accounting Office review cited earlier reviewed the Chase study alone, and therefore reviewed no case studies. The General Accounting Office, in its review, made the following recommendation to the administrator of NASA:

> Future evaluation studies should look at specific innovations, their effect on specific industries, and the process by which NASA expenditures for research and development improve productivity in the economy. In other words, some of the more important innovations, rather than the total budget, could be examined, and individual technological improvements in individual industries, rather than gross national product figures, could be studied. GAO believes that such studies would give the Congress a more accurate picture of what taxpayers are getting for their money.[88]

The above GAO recommendation, made in review of a report which included no case studies of the type GAO suggested, may have been appropriate in its context. However, because the two aggregate productivity analyses are about eight years and three years old respectively, and because the case studies are still somewhat scattered, and do not include any studies which use productivity analysis (or production function analysis) at the industry level rather than for the aggregate economy, it appears that both of the two broad categories of analysis described here could be pursued much further—both in parallel and in combination. If NASA-sponsored analysis of the economic effects of R&D were to stop with the documents cited here, NASA might soon fall far behind the frontier of such economic analyses.

F. Case Studies—Regional and/or Industrial Effects Analysis

In addition to the case studies described above, there are at least two documents which might be considered case studies by some definition, but which are extremely limited in any meaning for analysis of a na-

[88] U.S. General Accounting Office. Op. cit. p. iii.

tional R&D program. The Midwest Research Institute study attempted to provide in its part II and part III the beginning of a microeconomic rather than macroeconomic analysis. In addition the GAO recommended, in the context of its review of the Chase study, additional microeconomic or sectoral or industrial analysis—not necessarily as a substitute for, but as a supplement to, macroeconomic analysis such as provided by MRI and by Chase. The microeconomic or sectoral or industrial analyses done so far in supplement to the macroeconomic analysis may require substantial further development. But the needed sectoral analysis is not provided by certain types of sectoral or regional studies, or by studies which are both sectoral and regional simultaneously. The two documents described here originated either in the aerospace industry, or in the aerospace industry press. Both of the documents focus upon a specific region; in both cases, coincidentally, this region is the State of California.[24]

Studies of these kinds have a serious defect, when viewed from a national policymaking perspective. Simply put, they are exclusively concerned with the relationship of the economy in a particular region and/or industry of the United States to the spending by NASA. Studies of such types would perhaps be no less and no more parochial if they originated from any of the other 49 States.

The Rockwell International Report, "Impact of the Space Shuttle Program on the California Economy," is at its heart the same sort of analysis (performed for the State of California) that Chase Econometrics performed in its section 2, with one important exception. The Chase short-run macroeconomic demand study for the national economy analyzed the impact on the economy, in employment and inflation, of a shift of a certain amount of Federal expenditures to NASA R&D from all other Federal budget categories. As was described earlier, Chase computes very small effects from such a shift. The Rockwell report also computes employment and income effects—but for the California economy. The Rockwell paper does not describe a shift of Federal expenditures from one category to another within the State of California. Rather, the Rockwell paper assumes a net increase in Federal contracting and procurement in California as a consequence of the Space Shuttle program. It does not assume that the contracts let in California for Space Shuttle R&D are offset by reductions in Federal spending in any other category in California. Thus one must assume, though the Rockwell report does not say, that the Federal funds for those contracts either are shifted to the California economy from the economy of the other 49 States, or that the funds for the Space Shuttle contracts in California are obtained through increased Federal borrowing (increased Federal deficits).

Whereas the Rockwell paper is concerned only with the direct demand effects on employment and income in a region, the Holman and Konkel paper is concerned with the direct demand effects on a specific industry in that region, namely the aerospace industry in California. Both of these papers are of fully legitimate interest to the residents of California in general and to those employed by the aerospace industry

[24] Impact of the Space Shuttle Program on the California Economy. Space Division. Rockwell International. December 1974. 16 p.
Mary A. Holman and Ronald M. Konkel. "Space Employment in Los Angeles: A Declining Role in the Aerospace Industry?" California Management Review, Fall 1968. pp. 23–30.

in California in particular. They would certainly be of profound interest to almost all elected officials in California, just as similar reports from another State would be of great interest to elected officials of that State. But the short-run employment and income impact analysis of these papers suffers from the same limitations as direct demand analysis at the national level, with the added danger of the "fallacy of composition." To illustrate: if a national policymaker read these two reports, and concluded from them that the added income and employment benefits of added NASA expenditures in California also conferred similar economic benefits upon the rest of the Nation, that national policymaker would have engaged in the fallacy of composition, even though the authors of the Rockwell paper in particular carefully skirt such a conclusion. The authors of the Rockwell paper are careful to exclude the value of subcontracts awarded outside the State, and the purchase of materials from outside the State, from the overall employment multiplier effect which they calculate. So there is no fundamental flaw in the Rockwell paper, as an analysis for California. From a California perspective the Rockwell paper makes the following important point:

> While leakages [out of state subcontracts and materials purchases] reduce the economic impact on the State, it is important to stress that, because of aerospace specialization within a highly diversified economy [the California economy], major contract awards to California firms will have a greater impact on the State economy than if such awards were made to firms in States having less reliance on the aerospace industry, or less diversified economies.[86]

This valid but carefully limited conclusion may be interpreted as meaning that a Space Shuttle prime contract awarded in California is likely to generate smaller employment and income effects in the other 49 States than it might if it were awarded in a State other than California. This comes about because the California economy, if it is more diversified and self-sufficient, has less need (and opportunity) to spread its subcontracts and materials purchases among suppliers in more distant markets in other States. If California as a consequence captures a greater than average share of the income and employment ("multiplier") effects, other States will gain accordingly less. In terms of both subcontractor and material-supplier activity, and in terms of the household expenditures of aerospace workers, a larger proportion of the direct economic effects, and the multiplied economic effects, of a prime contract let in California is likely to remain in California because more of the things required by the aerospace industry and by aerospace industry workers, are available within the State, than might be true in some other State.

Thus, one may conclude that studies and papers of the type just discussed, regardless of the particular State or region for which they might be done, do not reach the more fundamental issues discussed in the earlier portion of this chapter.

G. Effects in the Long Run and Short Run, Direct and Indirect

The discussion above includes the short-run national effects of a shift of expenditures to NASA R&D from all other Federal expenditures. It includes the long-run product supply effect of increased levels

[86] Rockwell International. Op. cit. p. 16.

of technology arising over many years following a sequence of expenditures on NASA R&D. The Chase report computes, in its section 4, the national macroeconomic impact of NASA R&D spending, when both the short-run demand effects, and the long-run supply effects, are taken into account. In the Chase study's section 4, both the short-run demand effects and the long-run supply effects of a $1,000,000,000 increase (not just a shift) in NASA R&D expenditures is analyzed. That is, instead of increasing the NASA budget by decreasing some other Federal budget items, as was done in section 2, in section 4 Chase computes the effects of increasing the entire Federal budget by $1,000,000,000 and allocating that $1,000,000,000 entirely to NASA and maintaining that annual funding level increment over a period of time. Chase concludes:

> that a $1 billion increase in NASA spending has approximately the same effect on aggregate demand and employment during the first two years as would a similar increase in other purchases of goods and services by the government, although the multiplier effects are larger than those which we obtain for tax cuts or increased transfer payments. However, the differences over a ten-year span are much different. While most types of Government spending add to aggregate demand without increasing aggregate supply, and hence eventually contribute to inflationary conditions, spending for R&D actually increases productivity and aggregate supply a sufficient amount so that the rate of inflation is lowered. While we have shown that this is also true to a smaller extent for other types of R&D spending, it is not true for those types of spending which do not increase productivity at all. Once again, these types of simulations can be calculated only with the macroeconomic approach.[36]

With respect to the long-run effects of increased productivity computed in this macroeconomic model along with the short-run demand effects of increased spending, Chase concludes as follows:

> [I]n the long run, [NASA R&D spending] expands the production possibility frontier of the economy by increasing the rate of technological progress. This improves labor productivity further, which results in lower unit labor costs and hence lower prices. A slower rate of inflation leads in turn to a more rapid rise in real disposable income, which permits consumers to purchase the additional goods and services which are being produced.
>
> Turning to the specific figures, a $1 billion sustained increase in NASA R&D spending will raise real GNP $23 billion by 1984, raise labor productivity by 2.0 percent and lower the level of the consumer price index by 2.0 percent. The unemployment rate will decline by 0.4 percent, and . . . 0.8 million new jobs will be created because of a more rapid expansion of the labor force. It should be noted that the demand component of increased spending results in only a $2 billion increase in real GNP by the tenth year, with the remaining $21 billion due to the permanent improvement in the level of technology.[37]

Both the Chase report and the GAO review of it indicate that further work is required to better define, and to make more certain, the magnitudes and the conclusiveness of the Chase results. The Midwest Research Institute study of aggregate productivity change is now eight years old; the Chase report is three years old.

The above summaries of the case study literature on specific technological effects indicate that productivity improvement analysis of specific industries is still in a very spotty and rudimentary state, even though they begin to substantiate the aggregate productivity results of Chase and MRI. The analysis of aggregate productivity is a very lively field of economic research, and activity in this field has

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[36] Chase. Op. cit. pp. 97–98.
[37] Ibid. pp. 118–119.

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been substantially stimulated in recent years by concerns over the productivity of energy. Without a continuing effort to extend and to update and to further synthesize the results so far obtained, the studies which form the background-in-literature for this present discussion rapidly may become obsolescent. It is possible however that the present review, comparison, and partial synthesis of the documents cited here, may suggest further extensions of the work now available.

H. Summary—What Do We Know Now About Economic Benefits From NASA R. & D.?

The studies reviewed here may be summarized in the following way. First, short-run demand effect analyses of the national type are relatively unimportant, and those of the regional type are probably misleading, for the purposes of national policymakers.

Second, NASA R&D probably has had positive national output productivity effects measurable in the aggregate, although differences and uncertainties remain over both methods and magnitudes. Because of the statistical problems which were raised in the GAO review, and which have not been answered in any subsequent statistical study, aggregate economic effects of the magnitude suggested by Chase cannot be said to have been conclusively demonstrated at the aggregate level.

Third, the case studies show very substantial technological improvements to a wide variety of industries arising from the primary technology applications of both communications and environmental satellite systems.

Fourth, the case studies of secondary effects suggest perhaps innumerable improvements in technology whose tangible and intangible benefits in the aggregate may be large, although their quantification as economic productivity gains is rudimentary at best.

Fifth, the Chase and Midwest Research Institute studies, together with the supplementary case study material provided by NOAA and Mathematica, provide the framework of an integrated demand and supply analysis. The aggregate economic analysis is supported and lent credibility by the case studies.

Sixth, however, much remains to be done to gain a fully conclusive picture, especially of the effects of *future* NASA R&D on the economy.

Seventh, although the General Accounting Office did not emphasize this, aggregate economic studies and industrial case studies can be continued both in parallel and in combination.

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Press contact: Roz Boyle (212) 560-3016

THE MACNEIL-LEHRER REPORT

Dumping Space

In New York

ROBERT MacNEIL ..... Executive Editor
Dr. CARL SAGAN ..... Cornell University

In Washington

JIM LEHRER ..... Associate Editor
JAMES BEGGS ..... Administrator, NASA
GEORGE KEYWORTH ..... Presidential Science Advisor

Producer ..... MONICA HOOSE
Reporter ..... MAURA LERNER

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THE MacNEIL/LEHRER REPORT **Air Date:** November 4, 1981

Dumping Space

[Tease]

SPACE SHUTTLE LAUNCH CONTROL *[voice-over]*: T minus 40 seconds. The development flight instrument recorders are on. T minus 35 seconds. We're just a few seconds away from switching control to the computer sequencer in the orbiter. T minus 31 seconds, and we have held.

ROBERT MacNEIL *[voice-over]*: Only 31 seconds before lift-off, the second launch of the space shuttle runs into a snag. Now NASA's biggest program, will the shuttle soon be NASA's only program?

[Titles]

MacNEIL: Good evening. Billions of dollars worth of the world's most advanced space technology was grounded today, apparently by a humble mechanical problem — a clogged oil filter. That caused computers to stop the scheduled launch of the space shuttle Columbia, in case the auxiliary power units that swivel the shuttle's main engines would not work. The launch will be delayed for about a week. Today's mishap comes as the shuttle is being made the target of increasing criticism in the scientific community. The criticism is not directed at the successful space shuttle itself, but at the fact that it's eating up more and more of NASA's budget just when that budget is being cut by the Reagan administration. Critics say the space agency's preoccupation with the shuttle will drastically change NASA's mission, killing off its pioneering role in space exploration and advanced scientific research. Tonight, what's left for NASA in space? Jim?

JIM LEHRER: Robin, for years the U.S. space program operated pretty much with an open checkbook. Unlimited funds were available to act on the unlimited imaginations of American space scientists. No more. A decline in the thrills and glory of early manned space flight had already brought some limits. Now the crunch over federal budgets and spending priorities has brought even more. NASA currently has a $6.1 billion budget, but there are reports the Reagan administration wants to trim $367 million off of it this year and $1 billion more from projected budgets in each of the next two years. More than half of its funds are dedicated to the space shuttle program, and its costs are supposed to go up in the next three years, thus making an even bigger bite of the total pie. That could result in the scrapping of other projects NASA has underway or under consideration — everything from Voyager II's look at the outer planets in a 1985 mission to Jupiter to further research into aeronautics. A hoped-for mission to photograph Halley's Comet when it comes into view in 1986 is already believed dead as is a mission to study the sun. Matching available money with all of these projects is the job of James Beggs, the head of NASA. He was appointed administrator in July, coming from the General Dynamics Corporation, where he was executive vice-president for aerospace. First, Mr. Beggs, the news on the space shuttle. Was what happened today a major complication, a major problem?

JAMES BEGGS: No. What we're up to is flying developmental flights, which we do with all new airplanes. This is an airplane, a flying machine. We ran into a developmental problem which I believe will be minor, but it is something that you have to worry about and so we felt we had to scrub the flight and go back and find out what was wrong. Basically, as you described it, we had a high pressure in an oil— a lubrication-oil system. Not serious, but enough so that we worried because the system that it was lubricating is one of the key systems in getting us back to earth.

LEHRER: What are the odds on it taking off next week?

Mr. BEGGS: Very good. We have a corrective action now underway. It will take about six days, and we believe we'll be ready to fly next Wednesday or maybe Thursday. If we run

into a little bit more difficulty in replacing pieces and parts, because it is in the aft-end of the vehicle where it's kind of tight. We've got the plumbing for all the main engines back there, so it's difficult to get in there and work. But if we can get in and do what we expect to do, we think about a week.

LEHRER: Did today's problems cast any doubts on the basic idea of the shuttle, the idea of a reusable spacecraft?

Mr. BEGGS: Not at all. As a matter of fact, I think what we ran into today is the kind of thing that really indicates the efficacy of the system. What we have is, to be sure, a very complex system, but a system which has been designed so that we can monitor every piece and part of it, so that we can work on every piece and part of it should we run into difficulty. The fact that we were able to halt the countdown and to pinpoint the trouble in a matter of about three-quarters of an hour indicates that we know the vehicle very well. The problem that we have is simply one of insuring that we can service the vehicle in a quick, ready, routine way and make it fly. We will be able to do that. We say we are going to go operational in about a year or a little less. We will be able to do this, we feel sure, because of the fact that we are, in the four developmental flights, uncovering the various service problems that we have.

LEHRER: Now, is the shuttle secure in terms of secure financial aid, no matter what happens to the NASA budget over the next three years?

Mr. BEGGS: Well, when you say "no matter what happens to the NASA budget," I can't judge that.

LEHRER: Right.

Mr. BEGGS: But, in terms of the commitment of this administration, yes, it's secure.

LEHRER: Is there a possibility— looking at it from the inside, where you have to look at it from, is it a possibility that the shuttle may, in fact, end up as the only major NASA program?

Mr. BEGGS: No, I don't believe that. We have had in the NASA program what we like to describe as a balanced program. The shuttle will reach its maximum expenditures in the next three years. We'll be spending something over $3 billion a year for the next three fiscal years, and so it is eating a substantial part of the budget, but we still believe we'll maintain the programs intact. The programs, of course, are, in addition to the manned program, the space sciences and planetary exploration, the applications program and the aeronautics program.

LEHRER: Well, let's go through some of those specifically. I mentioned them at the beginning. For instance, Voyager II and its 1986 and 1989 target to photograph some outer planets. Is that going to go ahead?

Mr. BEGGS: Of course. We're not going to fly two billion miles and not take pictures.

LEHRER: Okay. What about the Jupiter mission in 1985?

Mr. BEGGS: I think the Galileo-Jupiter mission remains intact in the budget.

LEHRER: What about the basic research in aeronautics that goes on in your facility in Cleveland?

Mr. BEGGS: Well, there are three centers that are associated with basic aeronautical research. In addition to Lewis in Cleveland, there are Ames out in the South Bay Area in San Francisco and the Langley Center just south of here in Langley, Virginia. Those centers have, since 1915, conducted an extensive program of basic research and they remain intact. The real question there that has been examined and is still being examined is, how much prototype work or actual flying of hardware that we do. But the major facilities, and NASA is the repository of the major aeronautical facilities of the country, which exist in those three centers and which serve the industry and the university community in aeronautics, remain

very well alive and doing very good work.

LEHRER: Well, Mr. Beggs, it sounds to me like you're saying that you're going to be able to continue to do everything with less money. Is that what you mean?

Mr. BEGGS: No, I'm not saying that. NASA has, since about 1972, had a reduction in buying power. If you go back to 1972, the NASA budget was somewhere between $3.3 and $3.4 billion, and it has been reduced almost every year since that time. If we had the same buying power that we had in '72, we would have over $7 billion now, so we're operating with less money. We've reduced our manpower from what was then about 33,000 or 34,000 civil service people to about 22,000. So we've had a substantial cutback. We believe that we still have a very viable program at that level. Further reductions from that would be— would be problems to us, and it would mean that we would have to examine the various program areas and decide which we might have to give up. But right now, with the budget we have in '82, and with that we have in prospect in '83, we have adequate funds to continue that balanced program that I described.

LEHRER: Thank you. Robin?

MacNEIL: Last month, two scientists appealed directly to the White House to save key parts particularly of NASA's planetary exploration program. One of them was Carl Sagan, author, lecturer, professor of astronomy and space at Cornell University, and host of the PBS-TV series, "Cosmos." Mr. Sagan, first of all, are you reassured by what the administrator, Mr. Beggs, has just said?

CARL SAGAN: At least a little bit. I mean, it would have been monstrous to turn off the Voyager cameras when all the money had been spent in flying for the first time past Uranus and Neptune, and Galileo is the only approved mission of this decade to explore the other planets. There were dozens in the decades of the '60s and the '70s. So I'm slightly reassured by this, but it's still, if nothing more than this is done in space science, it's an exceptionally spare and ugly, dangerously small budget.

MacNEIL: In what way "dangerous?"

Dr. SAGAN: Well, in several respects. One is that the teams of engineers and scientists who have created this remarkable American accomplishment of exploring every planet from Mercury to Saturn, every little light in the sky that moved, known to our ancients. For the first time in human history, they've been explored close up and with some scientific rigor. For us to back off from that historically significant program seems to me exceptionally short-sighted.

MacNEIL: But Mr. Beggs said that those programs of the space sciences and planetary exploration will remain intact.

Dr. SAGAN: Well, it depends on which programs we're talking about. As I said, in the '60s and '70s there were dozens in each decade. In this decade there is one. I'm delighted that that one is not being canceled.

MacNEIL: That's the Voyager?

Dr. SAGAN: No. Voyager—

MacNEIL: The new Galileo one to Jupiter.

Dr. SAGAN: That's Galileo, yes. You see, we have the sense, from the enormous success and the great popular attention devoted to Viking at Mars and Voyager to Jupiter and Saturn, that things are going splendidly well, but that's the— we are the beneficiaries of decisions made in the '60s and '70s, because the lead times are so long for these missions. There are no new starts in this decade, with the single exception of Galileo, in planetary exploration, and that worries me greatly.

MacNEIL: Well, is what worries you the fact that no yet newer ones are being planned, or

that things already planned are being canceled, and can you name some specific—

Dr. SAGAN: Well, there are different levels of planning, but for example, Halley's Comet is an astronomical object fabled in song and story. It will approach the earth in 1986. We have the capability for the best exploratory program of Halley's Comet of any nation on the planet. The United States will not — unless a decision to the contrary is made essentially a week from Tuesday — explore Halley's Comet, while there will be a joint Soviet-French set of spacecraft to examine it. There will be a mission from the European space agency, and Japan will launch its first planetary mission.

MacNEIL: Well, if all those countries are doing it, won't international science, and therefore American scientists, benefit from the knowledge they reap?

Dr. SAGAN: No question about it. And my sense that these scientific exploratory programs should be done in the name of all the people of the planet earth is very strong. But the United States has some remarkably potent experience and capabilities, and this is an exercise which harms no one, which is widely acknowledged all over the world as a benevolent aspect of American technology, even in nations which disagree with us on virtually everything else. And what's more, we have some particular capabilities because of the enormous experience we have that no other nation has to perform such exploratory ventures. These are explorations which pump high technology, which have enormous public appeal— for example, there's an organization called The Planetary Society which has 100,000 members devoted only to interest in planetary exploration. And it's a venture of enormous historical significance. I think that 1,000 years from now the particular political crises that we're so focused on will be as obscure as the causes of the War of the Austrian Succession are to us today. But what will be remembered about this time — provided we don't destroy ourselves — is that this is the moment when we first set sail for the planets.

MacNEIL: A large part of the NASA budget is going into the space shuttle, as we said, and as the administrator has confirmed — $3 billion or so a year. What is wrong with putting such a large part, in your view, into the space shuttle?

Dr. SAGAN: Well, for one thing, the space shuttle is, to a significant degree, pumped by military requirements. And whether that's good or bad is a separate issue, but it seems to me this is a case of borrowing or stealing from the poor — namely NASA — to benefit the rich, namely the Department of Defense. The NASA budget is a very tiny fraction of the Department of Defense budget and yet it is NASA which has to develop the launch system for Department of Defense reconnaissance and other satellites. And so I think that's one thing that's wrong. This country has very few places where we are acknowledged world leaders, especially in activities that everybody says benefits the entire population of the planet. To take away from that very small pot of money and give it to the Department of Defense, which has such an enormous budget — over $1 trillion for the next few years — seems to me a serious mistake.

MacNEIL: Well, thank you. Jim?

LEHRER: President Reagan has given his White House Office of Science and Technology the major assignment of reviewing NASA and where it should go from here. The head of that review group is Mr. Reagan's science advisor, George Keyworth. He is a nuclear physicist who headed the Los Alamos National Laboratory in New Mexico before joining the administration. Mr. Keyworth, Dr. Sagan says that the spare space program that the United States is now working on is dangerous. Do you disagree?

GEORGE KEYWORTH: The spare space program?

LEHRER: He called it "the spare space program," that's so spare.

Dr. KEYWORTH: I beg to differ. And let me back up a little bit in perspective. Our administration is committed, I think, to maintain the leadership that the United States has today across the spectrum of science and technology, including space. Today we have a new

capability inherent in the shuttle. It's very different than what we've had for the last 10 or 15 years. What we are trying to do is to utilize the shuttle to develop some new areas of space science. Remember, the solar system, as interesting as its origins and evolution has been and will continue to be, is only a very small part of the universe. There's an enormous new field of space science that can be addressed with the shuttle.

LEHRER: Yes, but Dr. Sagan says that it's primarily the military priorities that have made the shuttle such a big priority and that NASA's civilian responsibility is being pushed aside as a result.

Dr. KEYWORTH: I think that we are still continuing to focus primary emphasis on the entire space program, upon the science and the civilian applications, and I think that's probably what continues to occupy Jim Beggs as primary considerations, for example.

LEHRER: What about his concern about no new projects, that back in the '60s and '70s there were 10, 12, whatever, new space exploration projects? Now there's only one new one on the boards, and that's Jupiter in 1985.

Dr. KEYWORTH: Well, I'll use his point to emphasize what I was trying to say initially about a new space program. It's true that Galileo is the only new start in planetary science, but let's look at the space telescope, which will be coming— will be launched in 1984. I think this is perhaps the single most exciting bit of space science that has ever been undertaken by us or any other nation.

LEHRER: And that's going to stay, right, as you understand it?

Dr. KEYWORTH: Very much so.

LEHRER: I see. Now, what is the scope of the review you're doing of NASA and the space program for the President? Is it a long-range, "where should NASA go," or is it a short-range, "how are we going to live with the budget cuts?"

Dr. KEYWORTH: Oh, it's very long range. First of all, it really was begun and initiated by the President out of context of the budgetary considerations. The objective is really to look at the next 10, 15, 20 years of our space program based upon this new capability inherent in the shuttle. What are we going to do? What is our balance going to be between space science, between applications, between planetary science and astrophysics, and what are the directions that we should begin now and emphasize in the future?

LEHRER: And when is your review supposed to be finished?

Dr. KEYWORTH: Oh, no firm deadlines, but I think we'll probably be finished formally within a matter of months.

LEHRER: And is the President himself going to make the final decision on this when he goes to Brother Beggs and says, "Look, here's what I think NASA ought to do?" Or is it going to be a budget thing made by the OMB?

Dr. KEYWORTH: No, no. It'll be a policy decision. The President asked me to initiate this study, working with the other agencies. I will report to him with our joint perspective and perhaps my recommendations, but the decision, I assure you, will be the President's.

LEHRER: Are you as concerned as Dr. Sagan is over the decision not to go ahead with the Halley's Comet project?

Dr. KEYWORTH: No, I wish we could do the Halley's mission. I wish we could do a number of other missions, but I think we're going through a very healthy exercise right now in trying to identify the richest, the healthiest overall space program. And I think we have a — just as Jim Beggs said — a very healthy program laid out that we can afford to support.

LEHRER: And you're not concerned also, as he is, about dismantling the expert teams that are now in place at NASA or in conjunction with NASA?

Dr. KEYWORTH: Oh, no. This is a period of transition. I think we'll be putting emphases in some new areas and deemphases in some others. But, no, I don't see any wholesale dismantling or anything resembling it.

LEHRER: But right now it is, as you say, it's all based on the shuttle — the future, right? As we sit here now?

Dr. KEYWORTH: Oh, most heavily, yes.

LEHRER: Thank you. Robin?

MacNEIL: Mr. Beggs, your turn to be asked if you are reassured by what you just heard. Are you satisfied— you said a moment ago that if there were further reductions there would be problems. Has the White House reassured you that there are not going to be further big reductions?

Mr. BEGGS: Well, let me— let me direct myself to the basic question which Carl Sagan was talking to. And I'd like to make maybe two or three points. First of all, it is true that we had an extraordinary decade in the '70s in planetary exploration. It was a culmination of a lot of things that we had started about the time that we were reaching the peak of our Apollo program — the flights to the moon. And it resulted in many, many very important and very exciting projects, the last of which are the Voyagers. They're very important, very exciting, and very productive. They have asked a lot of questions and have addressed the scientific community to further exploration. That further exploration, which undoubtedly will be conducted over the next couple decades, will be the subject of intense study by NASA and by the scientific community. The amount of money that we devoted to those activities, as a percentage of the NASA budget, has remained about constant for the entire life of the agency. NASA became an independent agency in 1958. And for the little over 20 years that we've been in existence, the percentage of money devoted to space science and planetary exploration has remained about constant as a percentage of our budget. Now, we have in being the Galileo mission going back to Jupiter to probe the atmosphere of Jupiter, a very important scientific mission, which will answer a lot of questions which have been asked by the Voyager series and by the Pioneer series. We also have in existence the large space telescope which will enable us to peer out into the cosmos that Dr. Sagan has promoted so effectively and so well. And we have planning for another mission to Venus, which will come on in the latter part of the '80s, and so we still have what I consider to be a healthy planetary exploration of man's role in the earth and the cosmos. It is not as big as everyone would like, but then again, there is not a single program that is being conducted by the federal government that is as large as its proponents would like.

MacNEIL: Let me put that back to Dr. Sagan. You've heard the administrator say that the percentage of NASA's budget devoted to space sciences and planetary exploration remains the same as it has been.

Dr. SAGAN: Well, yeah, but the absolute value has been declining. The number of missions — lunar and planetary missions — in the decade of the 1960s was 24; in the decade of the 1970s, it was 14, and in the decade of 1980s is one or two. Now, that is a substantial decline. Dr. Keyworth said that we shouldn't forget about the space telescope as an historic— and that it would open up remarkable new windows to the universe, and I am a very major enthusiast of that space telescope. But the space telescope is not a new start of the Reagan administration or the 1980s. We are again the beneficiary of a new start made in the 1970s. The question is, because the lead times are so long, because scientists cannot forever wait, hoping that there'll be some new mission — they have to do something to support their families — the question is, what new, major starts in space science — apart from planetary exploration — are going to be done by the Reagan administration?

MacNEIL: Let's ask Mr. Keyworth. Dr. Keyworth, what new starts are going to be done?

Dr. KEYWORTH: Well, another one that I feel very enthusiastic about is what we call the

gamma-ray observatory. I think it offers, in addition to the optical, that is, visible-light capabilities of the space telescope, it offers us an enormous opportunity to understand and explore rapidly pulsing suns in the distant regions of our universe.

MacNEIL: Is that a new start by your definition?

Dr. SAGAN: Oh, if this represents a commitment to the gamma-ray observatory, I am, at least as far as this goes, delighted. Is that what's being said?

MacNEIL: Is that what is being said, Dr. Keyworth?

Dr. KEYWORTH: We're talking about a launch that would occur later in the decade, but, yes, I think we're all very committed to trying to maintain stimulus and development of the gamma-ray observatory, yes.

MacNEIL: Let me come back with Mr. Beggs to another question that Dr. Sagan raised. Are you happy, Mr. Beggs, about so much of your budget, which is a small budget by comparison with the Pentagon's, going to support and enhance a program of which the Pentagon will be a major beneficiary?

Mr. BEGGS: Well, I've got a quarrel with the basic premise there. The military is indeed a beneficiary of the shuttle, but the shuttle stands on three legs, only one of which is military; the other is commercial, and applications work; and the third is the space science and planetary exploration that we are talking— we have just finished talking about. The military is by far the minority of the number of missions in the mission model that we will be flying the shuttle. The shuttle is a means to an end. It's a transportation system. It will provide a routine, economical means of going into space and of exploring the various options that we have in the future to do the great things that we must do. We have had an extraordinary history in the last 20 years which, as I said earlier, points out a number of directions that we'd like to go. We felt back in the early '70s that we needed a more economical transportation system to exploit the next couple decades. That's the shuttle. Now, we are coming to the point where we are about to make that operational and we must, we have to, we have no choice here— we must finish that program and we must finish it so that it gives the promise that it offered in the beginning.

MacNEIL: We have to—

Mr. BEGGS: When we do— when we do, we will have a system that is not only useful for the military, but is extraordinarily useful for the commercial applications and science programs that we are going to have in the next couple decades.

MacNEIL: That's the end of our time, Mr. Beggs. Thank you very much for joining us. Thank you, Dr. Keyworth, in Washington, and Dr. Sagan here. Good night, Jim.

LEHRER: Good night, Robin.

MacNEIL: That's all for tonight. We will be back tomorrow night. I'm Robert MacNeil. Good night.

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B. TECHNOLOGY

THE ECONOMIC BENEFITS OF OPERATIONAL ENVIRONMENTAL SATELLITES

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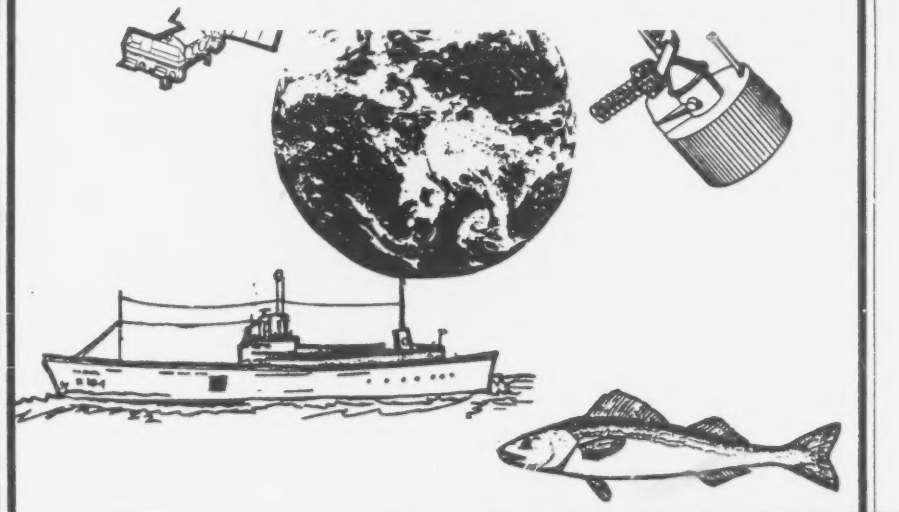

by

W. JOHN HUSSEY

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C.

THE ECONOMIC BENEFITS OF OPERATIONAL ENVIRONMENTAL SATELLITES

by

W. John Hussey*

Abstract

Satellite observations of the atmosphere on a global scale began 23 years ago. In the intervening period, satellite sensors and operational techniques for the use of the data has evolved to a high degree of proficiency. This paper identifies and attempts to quantify, to the extent possible, many of the current benefits and uses being derived from the United States' Operational Environmental Satellite System.

The initial paper on this subject was published by W. John Hussey and E. L. Heacock in April 1978 and presented at the Fourth Annual Convention of the Eastern Economic Association in Washington, D.C. Subsequently, there has been considerable interest in the evolving benefits of environmental satellites and the primary benefits discussed in the 1978 paper have been updated and included in this paper. In addition, many other unique uses of environmental satellite data are discussed in this paper.

The benefits discussed herein are evidence that the operational environmental satellite has earned its place as an irreplaceable weather and ocean observing tool. These satellites are making major contributions towards the saving of lives and property from natural disasters and improving the efficiency of many sectors of our national economy.

*Chief, Satellite Services Division; National Environmental Satellite, Data, and Information Service; National Oceanic and Atmospheric Administration; Department of Commerce; Washington, D.C.

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III. Summary

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1. Operational Environmental Satellite Program Mission Objectives

The Nation's operational environmental satellites are operated by the National Oceanic and Atmospheric Administration's (NOAA) National Environmental, Satellite, Data, and Information Service (NESDIS). The mission objectives of this operational satellite program include:

I. Monitoring the atmosphere regularly and reliably on a global basis, day and night, with direct readout to local ground stations around the globe within radio range of the satellites.

II. Sounding the atmosphere regularly on a global basis and providing quantitative data for numerical weather prediction services.

III. Continuous monitoring of environmental features in the western hemisphere, and the collection and relay of environmental data from remote platforms such as buoys, ships, automatic stations, aircraft, and balloons.

IV. Applying environmental satellite data for the purpose of improving environmental services.

2. Geostationary Satellite System

NOAA's Geostationary Operational Environmental Satellite (GOES) system includes two satellites, the ground data acquisition station, and a centralized data distribution system. The first satellite in this system, NASA's Synchronous Meteorological Satellite (SMS-1), a prototype for GOES, was launched May 17, 1974. The latest in the SMS/GOES series, GOES-5, is the seventh operational geostationary spacecraft to be operated by NESDIS. The next GOES satellite, GOES-F, is scheduled to be launched from Cape Canaveral in April 1983. Two additional GOES spacecraft are being built by the Hughes Aircraft Company. These have been designated GOES G and H and are scheduled to be launched in 1986. The next generation geostationary environmental spacecraft called GOES NEXT is in the preliminary planning stages. It is scheduled to be available for launch in mid-1989 to ensure continuity of geostationary coverage. The GOES NEXT series is planned to cover a 12 year period beginning in 1989.

The operational system consists of two satellites; GOES West located over the equator at 135° West longitude and GOES East located at 75° West longitude. GOES West observes North America and the Pacific Ocean to west of Hawaii and GOES East observes North and South America and most of the Atlantic Ocean. These geostationary spacecraft are in circular orbits at an altitude of approximately 35,800 km. (22,240 miles).

The primary instrument carried by GOES satellites is called the Visible Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS). This instrument, first carried into space on GOES-4, provides the traditional visual and infrared imagery of cloud cover and the earth's surface. In addition, VAS provides measurement of infrared radiation which can be used, with known atmospheric properties, to calculate atmospheric temperature profiles over selected geographic areas. It can also produce images in multiple IR spectral bands instead of the single band produced by the VISSR. This new capability is called multispectral imaging and has proven very useful in depicting the amount, distribution and movement of water vapor at various levels.

The VAS provides a full disc view of the earth every 30 minutes. More frequent images can be obtained at the sacrifice of spatial coverage. The visible channel provides high resolution (about 1 km) daytime images. The infrared channel provides lower resolution (about 8 km) day and night images. The GOES images are processed through the NESDIS Central Data Distribution Facility, either as a full disc image or a sector of this full disc image. These products are routed to Satellite Field Services Stations (SFSS) for analysis with further routing to National Weather Service Forecast Offices and other users.

The SFSS's are located at Washington, D.C.; Miami, Florida; Kansas City, Missouri; San Francisco, California; Honolulu, Hawaii; Anchorage, Alaska and Slidell, Louisiana. Each SFSS provides regional analysis, interpretation, and distribution of the VAS images to meet a wide variety of environmental needs. A most important service is the near-continuous viewing of the development and movement of severe weather systems such as hurricanes and thunderstorms. An extension of the GOES image distribution service is the "GOES-TAP" system. Established by NESDIS in 1975, "GOES-TAP" allows Federal, state, and local agencies, television stations, universities, and private industry to receive an inventory of GOES satellite images directly from the nearest SFSS. In addition, the GOES satellites broadcast environmental products to remote locations using the Weather Facsimile (WEFAX) System.

The GOES satellites also carry a Data Collection System (DCS) which collects and relays environmental data obtained by remotely located sensing platforms such as river and rain gauges, seismometers, tide gauges, buoys, ships, aircraft, and automatic weather stations. Each operational GOES spacecraft can accommodate data from more than 10,000 platforms each six hours. Data are normally transmitted in a self-timed mode or upon interrogation by the satellite. Data may also be transmitted under emergency conditions in which the platform transmitter is triggered whenever an observed parameter exceeds a predetermined threshold value. About 3,600 + platforms now provide environmental data to users in the United

States and Canada. The geostationary satellite DCS provides a near-instantaneous source of information for many applications such as river level and flood monitoring and forest-fire index measurements.

Also included in the GOES instrument complement is a Space Environment Monitor (SEM) which provides measurements of solar activity for detecting solar flares, the intensity of the solar wind, and the strength and direction of the earth's magnetic field. The SEM data which is included in the satellite telemetry data stream is received at the NOAA Space Environment Services Center (SESC) in Boulder, Colorado. These data are separated out of the telemetry stream and processed in the SESC data base. When significant solar events are detected, the SESC issues warnings to a number of users throughout the United States. Routine forecasts of solar activity and its implications such as interference with high frequency radio transmissions, are also distributed by SESC.

3. Polar Orbiting Satellite System

NOAA's operational polar orbiting satellite system is called the TIROS-N/NOAA series and consists of two satellites and the ground data acquisition and processing systems. The first spacecraft in this series called TIROS-N was launched on October 13, 1978. There are two polar orbiting satellites currently in operation providing global coverage at different times of the day. NOAA-6 is in a morning orbit (0734 local equator-crossing time descending) and NOAA-7 is in an afternoon orbit (1453 local equator-crossing time ascending). These satellites are in sun-synchronous orbits at altitudes of 808 km and 847 km, respectively. The orbital period is 102 min. which equates to 14.2 orbits per day.

The next TIROS-N/NOAA satellite, NOAA-E, is scheduled to be launched from Vandenberg AFB, California in March 1983. Three additional NOAA spacecraft are being built by RCA Astro-Electronics These have been designated NOAA F, G, and D and are scheduled to be launched in 1984, 1985, and 1986/87 respectively. Three other polar orbiting spacecraft, NOAA H, I, and J are in the planning stages.

The TIROS-N/NOAA series utilizes four primary instrument subsystems. These are:

1. Advanced Very High Resolution Radiometer (AVHRR)
2. TIROS Operational Vertical Sounder (TOVS)
3. Data Collection System (DCS)
4. Space Environment Monitor (SEM)

The AVHRR provides visible and IR image data for real-time transmission to direct readout users and for storage on the spacraft tape recorders for later playback. The AVHRR consists of five channels which provide data on daytime cloud cover, snow and

ice coverage, nighttime cloud cover and sea surface temperatures. The direct readout High Resolution Picture Transmission (HRPT) has a resolution of 1 km in all spectral channels. The Automatic Picture Transmission (APT) provides an undistorted resolution of 4 km. There are over 800 APT receiving stations and 76 HRPT receiving stations located in approximately 123 countries throughout the world.

Also available is on-board recording of the 4 km resolution data which provides Global Area Coverage (GAC). Selected on-board recording of the 1 km resolution data is available as Local Area Coverage (LAC). The recorded data is played back to the NOAA Command and Data Acquisition (CDA) stations located near Fairbanks, Alaska and Wallops, Virginia. The data are subsequently transmitted via a domestic communications satellite to the NOAA central data processing facility in Suitland, Maryland.

The TIROS Operational Vertical Sounder (TOVS) includes three complementary sounding instruments. These are:

1. High Resolution Infrared Radiation Sounder (HIRS/2)
2. Stratospheric Sounding Unit (SSU)
3. Microwave Sounding Unit (MSU)

The HIRS/2 provides data which permits calculation of temperature profiles from the surface to 0.1 mb ($\sim$215,000 ft.), the water vapor content of the atmosphere and the total ozone content. Data from the TOVS instruments are also broadcast via the direct readout transmission links. The SSU instrument is provided by the United Kingdom.

The Data Collection System (DCS) is provided by France. It is called the ARGOS Data Collection and Platform Location System. The ARGOS system provides a means to locate and collect data from moving platforms. The platform data are stored and relayed to the Suitland center where it is separated and relayed to the CNES Toulouse Space Center in France. There, the data are processed, earth located and relayed to the ultimate user.

The TIROS Space Environment Monitor (SEM) includes three detectors which measure solar proton flux, alpha particle and electron flux density, energy spectrum and total particulate energy distribution at spacecraft altitude. The data from the SEM are stripped out of the spacecraft telemetry stream and transmitted to NOAA's Space Environment Services Center (SESC) in Boulder, Colorado. These data are used to monitor the state of solar activity which has a significant effect on terrestrial communications, electrical power distribution, etc.

II. Activities Benefiting From Operational Environmental Satellite Programs

Following is a synopsis of several specific examples of the economic benefits and also intangible benefits, such as lives saved, which are derived directly from operational environmental satellite data or from a combination of satellite and "conventional" weather data. It should be recognized that many of these benefits are possible because of the operational nature of the environmental satellites. In other words, users can depend on the availability of these data today, tomorrow, and in future years. Therefore, users can afford to invest in special data handling and processing equipment, software, and techniques with confidence that these satellites will be available to provide the data they require year after year.

1. Ocean Current Navigation for Fuel Savings

Use of the swift Gulf Stream currents to increase northbound steaming speed is an old idea, but utilizing that idea has not been easy. The swiftness and great variability of the Gulf Stream position creates many uncertainties and hazards to navigation. Much of the uncertainty is created by eddies and meandering of the Stream. Meanders can be 250 miles across and the stream axis can move as much as 60 miles in a week.

A 1975 Gulf Stream Navigation Experiment conducted jointly by the EXXON Company and the National Oceanic and Atmospheric Administration (NOAA) showed that significant fuel savings can be realized by using timely satellite analyses of the Gulf Stream position for oil tankers navigating along the eastern seaboard. An improved NOAA satellite capability, operationally available with the launch of NOAA-2 in 1972, was infrared measurement of sea-surface temperatures. Enhanced infrared images representing sea-surface temperature differences clearly delineated the warm Gulf Stream in contrast to the colder shelf water. The joint EXXON/NOAA experiment was conducted to test whether using satellite-derived Gulf Stream analyses could improve navigation enough to realize significant fuel savings. NOAA analyzed the satellite infrared images of the Gulf Stream's western boundary called the "Western Wall"; and estimated the axis of maximum current velocities relative to the Western Wall. EXXON arranged for radio broadcast of the information to their tankers at sea.

Eleven EXXON tankers, steaming from the Gulf of Mexico to east coast ports and returning, participated in the experiment. Five were instructed to follow the usual navigational practices, which used or avoided the Gulf Stream in a relatively random manner. The other six were to use the NOAA satellite analyses for their navigation. In other words, the tankers were to transit within the Gulf Stream northward and avoid the Gulf Stream on their southbound journey.

The seven month study showed a very definite fuel savings for the six vessels using the NOAA data. EXXON, assuming a total of 15 tankers navigating by satellite data, projected savings amounting to 31,500 barrels of fuel oil. Using a 1975 cost of $11.50 per barrel, the EXXON study reported a potential annual fuel savings of around $360,000 for their company alone. Assuming a 1982 cost of $30.00 for a barrel of fuel oil, the estimated annual savings would be around $945,000 for 15 tankers navigating the Gulf Stream effectively. Use of satellite derived Gulf Stream position data is now standard navigating procedure for all ships of the EXXON fleet. Applications of this information by all coastal traffic of the U.S. merchant marine is possible and could result in significant savings of U.S. fuel resources. The analyses are made available by automatic telecopier and radio broadcasts.

A similar product is available for Gulf of Mexico navigation. A clockwise flow of warm water from the Yucatan Straits, around the Gulf, and out through the Florida Straits is quite strong. The coastward edge of the warm water in this "Loop Current" is marked by a thermal gradient which is great enough in the cold winter months to be discerned in the satellite infrared imagery. The NOAA Miami Satellite Field Services Station produces a Loop Current Bulletin (November to May) which aids ships in the Gulf of Mexico to use the Loop Current for assistance in a manner similar to the use of the Gulf Stream described above. These analyses are also available by automatic telecopier.

The Crowley Towing and Transportation Company of Jacksonville, Florida operates 60 vessels in the West Indies and Gulf of Mexico and has stated that accurate knowledge of the Gulf Stream and Loop Currents is vital to their operations. An on-going fuel conservation program has been enhanced by this satellite information with fuel savings of 20-40% obtainable when their 9000 Hp tugs are able to reduce engine rpm by 18%, with only small reduction in speed. They are experiencing up to $2000 per steaming day savings on their line haul tugs. Other Crowley barge sailings returning north from Cuba via the Santaren Channel utilizing the Gulf Stream to the utmost, are improving their average speed from 9.5 to 12.0 knots which on a bi-weekly basis saves 8 hours per voyage. This totals 192 hours per year or 8 days per year at an average equipment operating cost of $15,000 per day.

2. Commercial Fishing Industry

The NOAA Satellite Field Services Station at San Francisco has produced charts derived primarily from the polar orbiting satellites' Very High Resolution Radiometer (VHRR) infrared imagery depicting the location of thermal boundaries or "fronts" as part of an operational sea surface temperature analysis. It has been well documented by marine biologists and fishermen that certain species of fish are temperature-sensitive. Albacore (blue fin tuna) and coho (silver) salmon, the principal commercial fish found along the west coast, tend to congregate in nutrient rich waters in the vicinity of thermal fronts. Albacore are found in temperatures ranging from 16°C - 20°C, while salmon prefer temperatures of 11°C - 13°C.

Since 1975, the National Environmental Satellite, Data, and Information Service (NESDIS) has been issuing Sea Surface Temperature (SST) Frontal Charts from the SFSS in San Francisco to aid fishermen in locating these "productive" areas. In 1981 the SFSS began producing a sea-surface thermal analysis incorporating satellite-observed thermal features. Geographically, the area originally covered by the charts extended from 34°N to 49°N and from the coast to 128°W. Since 1981, only one area has been charted and that extends from 28°N to 40°N and west to 136°W. It is known that the food chain is often concentrated along these fronts, usually as a result of the seasonal upwelling process that takes place along the west coast of the United States. Charts produced when skies are cloud-free, have greatly assisted commercial albacore and salmon fishermen in locating fish productive areas. Results were so encouraging that the program was expanded to cover most of the West Coast.

The IR images, received up to four times daily, are enhanced using computerized tables to assist in the identification of the thermal gradients. The changes in temperature are represented by changes in the tones of gray in the enhanced satellite image. The frontal postions are analyzed directly on the image and then transferred to a marine navigational base chart. These analyses are produced twice a week. The latest chart is transmitted twice daily by radio facsimile from Point Reyes, California, and by automatic telephone telecopier.

Satellite images are also transmitted twice per day to the Seattle Ocean Services Unit of the National Weather Service. This unit produces a satellite derived thermal boundary and sea surface temperature analysis extending from 40°N to 52°N which is distributed to Pacific Northwest fishermen via a telecopier system, mailing list, and direct telephone briefings.

An example of how the fishing community has received this product is indicated in a quote from the Summary of Pacific Input to the Eastland Fisheries Survey prepared by the Pacific Marine Fisheries Commission as their input to the nationwide Eastland Fisheries Survey, a report to Congress dated May 1977. This report states (underscore added):

> "Commercial salmon and albacore trollers emphasized that the federal government should not be involved in developing new equipment and methods for locating fish with one exception. They support the use of satellite pictures which display temperature gradients and indicate that the federal government should continue to use existing satellites to provide this information. Present methods for developing and providing advisories are adequate and existing advisories for the albacore fleet should continue. More emphasis should be placed on provision of practical information such as water temperature, weather, and currents...."

The commercial fishermen are beset with a number of problems which include changing and more stringent regulations and increasing fuel costs. By delineating those areas which are often fish-productive through the use of infrared satellite imagery, a fisheries management tool is available whereby commercial fishing can become more efficient and thus more cost effective. Fishermen can disperse over larger areas when productive frontal locations are known thus helping to avoid overfishing small areas.

During the initial experiment in 1975, it was estimated that approximately 200 salmon and albacore fishing vessels were able to save $580,000 in fuel costs as a result of using satellite data. The albacore fishery has the most direct benefit from the satellite data since they are very temperature oriented. The salmon industry benefits to a lesser extent. Mr. Fred Jurick formerly of the NOAA Sea Grant Program, Marine Advisory-Extension Service at Humbolt State University in Arcata, California was a pioneer in the use of satellite data to directly support fishermen. Mr. Jurick correlated catches of albacore and salmon ranging from $2,000 to $14,000 directly to the use of the satellite derived thermal front charts. One commercial salmon troller stated that he caught an extra $10,000 to $12,000 of fish (which was about one-third of his total seasonal catch) as a direct result of using the thermal front charts.

If one uses the figures provided by the National Marine Fisheries Service, and places a modest savings of 10% on the fuel bill for each of 1000 fishing vessels in operation off the West Coast, the annual fuel savings for the fleet is $440,000. If one then adds a "catch advantage" of $2000 worth of fish per vessel (approximately 2 ton of albacore) due to time saved and improved location of the fish, one has an annual benefit of $2,440,000 to the fishing industry on the West Coast. This figure is conservative since there are more than 1000 vessels fishing off the West Coast.

In Alaska, the weekly Sea Surface Temperature (SST) charts are distributed by the Anchorage Satellite Field Services Station to approximately 200 users of which 65% are commercial fishermen/processors, 15% are Federal and state agencies, 10% are oil industry and 10% are research organizations. These SST charts provide guidance to commercial fishermen and fisheries researchers concerning the expected arrival of commercial species to Alaskan waters: herring (SST 4°C); red salmon (SST 7°C) in Bristol Bay; silver salmon (SST 11-13°C) in Southeast Alaska; and pink salmon (SST 11°C) near Kodiak Island thus saving travel time, labor and fuel costs. This information is being used for local fish inventory and migration studies and fish harvest forecasting.

NOAA sea surface temperature and ice condition charts derived from polar-orbiting satellite data have saved an Alaskan herring processing plant an estimated $7000-$8000 per day in wages and fuel costs. Using these data, the company determines where it should send its floating processing plant for herring runs. Multiplied by 8-10 processors over a month's time, the savings are subtantial. Commercial fishing for silver salmon around southeast Alaska has also been enhanced by the location of the 11°C isotherm. Catch increased from 50 to 200 salmon a day; again trolling costs (fuel, equipment and time) are significantly reduced.

Other Alaskan users are the king crab fishermen in the southern Bering Sea and Bristol Bay. In 1980, the king crab fishermen lost more than $3 million in crab pots due to untimely ice formation. These fishermen now use the satellite derived ice charts to determine when to retrieve their pots prior to ice formation.

On the East Coast, the swordfish is one of the few temperature-sensitive fish in the Atlantic. Swordfish prefer areas with temperatures ranging from 13° to 25°C. The East Coast fishermen supplement satellite derived data with information on water depth and the migration routes of the swordfish. The president of the Swordfishermens' Association stated: "Receiving these charts has resulted in a tremendous savings of time. We used to spend up to five days looking for the fish, and now we can go right to the place where the fish are located. When you figure that most boats

will use from 20 to 50 gallons of fuel an hour, you can recognize the savings involved. There are about 500 vessels in the swordfish fishing fleet."

For completeness and comparative purposes, the dollar value of all pelagic and benthic fish species caught in the major fishing regions within U.S. waters in 1981 are shown in the following table. Note that 62% of the dollar value of these species were caught in Alaskan and Californian waters. It is interesting to note that satellite data support to the fishing industry is utilized to a greater extent in Alaska and California than in any other major U.S. fishing area.

Value of All Pelagic and Benthic Fish Species Caught in 1981

	Dollar Value	Percent
Alaska	$ 639,797,000	43
California	275,196,000	19
Maine	196,854,000	13
Louisiana	193,549,000	13
Texas	174,787,000	12
	$1,480,183,000	100

Internationally, NOAA satellite-derived sea surface temperature data are used to aid commercial tuna fishing by the Portugese near the Azores and by a consortium of New Zealand companies and the Star-Kist Tuna Company fishing around northern New Zealand.

3. Agriculture Industry

A. General

A study published in 1973 by the Space Science and Engineering Center of the University of Wisconsin showed that improved weather information and forecasting could provide large economic benefits to the agriculture industry. The purpose of the study was to determine the value of improved weather information and weather forecasting to farmers and agricultural processing industries in the United States. The study, funded by NASA, was undertaken to identify the production and processing operations that could be improved with accurate and timely information on changing weather patterns. Estimates were then made of the potential savings that could be realized with accurate information about the prevailing weather and short term fore-casts for up to 12 hours. Improved weather information was defined to mean that a satellite observation not more than one hour old was available and was the basis for a current weather description and an accurate 12-hour forecast.

The growing, marketing, and processing operations of the twenty most valuable crops in the United States in 1971 were studied to determine those operations that are sensitive to short-term weather forecasting. Agricultural extension specialists, research scien-

tists, growers, and representatives of processing industries were consulted. Statistics from the U.S.D.A. Crop Reporting Board show that the value for farm crops produced in the United States was more than 26 billion dollars in 1971. The total value for crops surveyed in this report exceeds 24 billion dollars and represents more than 92 percent of total U.S. crop value.

A detailed study was made of the operations in the production and processing of vegetable crops to obtain precise estimates of the value of improved weather information. Vegetable processing industries of the North Central Region (Wisconsin and Minnesota) were contacted through the Wisconsin Canners and Freezers Association and a special weathercasting subcommittee was established. Meetings were held with industry personnel representing six large processors in these states to determine aspects of their operations that could be improved with more precise weather information and to develop procedures for estimating the value of this information. The company representatives utilized their field and processing plant records to determine losses resulting from unfavorable weather and to provide estimates of the savings that could have been realized with accurate short-term weather information. The entire agricultural process was considered in the survey from soil preparation and pesticide spraying operations to the harvesting of crops and the delivery of field products to consumers or food processors.

This survey of agricultural crops has indicated that improved weather information would have saved crop growers and processors $74,000,000 in 1971. Short-term forecasts from satellite data are of particular value for crops which yield perishable products and which require very precise production practices in order to insure marketability. The annual weather related loss in agriculture in the U.S. is estimated to be $12 billion. It is estimated that protectable losses through improved 3-5 day weather forecasts average about $5 billion per year. Regional agricultural advisories issued by the National Weather Service (NWS) are responsible for saving approximately $400 million per year in the NWS Western Region alone. These regional savings include:

- Raisin crop drying - harvest vs. cover - California ($800 million/year potential loss)
- Water removal from ripe cherries using helicopters ($124 million/year protectable loss)
- Grape harvest - Monterey County, California ($79 million/year bonus)
- Frost protection - Arizona ($500/acre savings)

- Planting impact in Washington State
  ($70 million/year savings)

- Weed and pest control - cost to re-spray due to rain washoff
  ($8-$10/acre)

In 1980, specially enhanced AVHRR data were used in a novel way to solve an agricultural problem in California. A local bee breeder, with the intention of relocating and expanding his operations, asked the San Francisco SFSS for help in determining the warmest daytime areas during the months of January through March. Warmer daytime temperatures increase bee activity. TIROS-N/NOAA-6 AVHRR IR images over the three-month period were enhanced to accentuate afternoon ground temperatures. Persistent warm areas were then located in the desirable counties, and these data were superimposed on maps detailing favorable bee habitats. Once an optimum correlation was made, the bee breeder contacted the land owners for possible rental space for the beehives.

B. Citrus Industry

When frost is expected in Florida on cold winter nights, the NOAA Satellite Field Services Station (SFSS) in Miami, Florida, provides specially enhanced GOES infrared images and interpretations to the National Weather Service which has responsibility for fruit frost forecasting. This capability was first successfully demonstrated in January 1976 and became an operational program during the winter of 1976-1977.

The enhanced satellite images show surface temperatures which are critical to freeze predictions. These ground temperatures, derived from images taken every 30 minutes over the entire southern citrus belt, are accurate within $\pm$ 1°C. Thus, the movement southward of the cold winter air and associated "freeze line" can be monitored and tracked every half hour. The Weather Service provides the observations and forecasted movement of the cold air to the citrus growers as soon as it is available.

The Florida citrus grower must decide whether or not to protect his crop upon receiving a forecast for temperatures below about 28°F. These protective actions usually include the firing of diesel heaters and/or the use of electrically operated wind machines. The grower must decide when to call in work crews, when to activate heaters and/or wind machines and how many heaters must be used. All of these decisions affect their operating costs and losses incurred from inadequate protection.

Protecting citrus groves is a very expensive operation, and needless heating can produce an exorbitant waste of fuel. There are approximately 750,000 citrus-bearing acres in Florida. On

"cold" nights, an average of 6 hours of heating protection is needed at a cost of approximately $830,000 per hour for fuel. This amounts to a potential $5,000,000 cost per night for the state of Florida if smudge pots and other frost prevention devices are operated because of expected temperatures near the freezing mark. The cost to have labor on duty waiting for specific satellite aided fruit frost warnings before lighting smudge pots and operating frost prevention devices is about 42¢ per acre or $315,000 per hour. Thus, the net potential savings for timely and accurate satellite freeze line forecasting is $515,000 per hour.

It is estimated that 1 to 2 hours of heating protection per "cold" night could be saved as a result of the use of the frequent satellite imagery. Assuming a reduction of 1½ hours average heating protection, the savings could amount to $770,000 per cold night. During the winter of 1976-77, a total of 64 cold nights were experienced. During the winter of 1977-78, 54 cold nights were experienced in the state of Florida. The average number of cold nights in Florida each winter is 35 to 40. The enhanced satellite images are used routinely to observe the movement of the "freeze line" to warn citrus growers via NOAA Weather Radio and a telephone communications network via county agricultural agents. The satellite enables a greater amount of temperature information to be acquired more frequently and passed on to the citrus growers in a timely manner.

The NOAA Satellite Field Services Station (SFSS) at San Francisco prepares a daily satellite image interpretation narrative tailored to the needs of the National Weather Service (NWS) fruit frost forecasters. Frost sensitive agricultural products grown in California amount to $3.7 billion per year. Advisory committees have estimated that the frost forecasts provided by the NWS are responsible for saving between 5 and 20 percent. The fruit frost forecasters have estimated that the satellite contribution to this savings of harvests would be between 0.5 and 1.0 percent, or between $15 and $40 million annually.

C. Hawaii Sugar Cane Industry

The harvesting of sugar cane is a process which is very dependent upon local weather conditions and benefits greatly from satellite derived forecasts. The Waialua Sugar Company on the island of Oahu has been using satellite imagery provided by the NOAA Satellite Field Services Station in Honolulu, Hawaii, to plan their harvesting schedule.

When a cane field is ready for harvest (about 2 years after planting), it is first deliberately set on fire and burned; the remains are then gathered and hauled to the mill. Weather is an important factor in this complex operation. Convection and trade

wind showers are the main weather hazards to the harvesting process. Burning must abide by State and Federal air pollution regulations. Tactical procedures for burning a particular field depend heavily on wind direction and speed. After burning, the remains must be harvested within 24-36 hours to avoid spoilage. Any significant rainfall during this critical period interferes with the movement of heavy harvesting vehicles in and out of the field. Typically, 50 to 100 acres are burned at one time, leaving burnt cane worth $250,000 lying in the field at the mercy of the weather.

The production manager of the Waialua Sugar Company, who is responsible for making the daily harvesting decisions, has said, "I look at the weather maps and listen to what they are saying on the broadcasts, but when I look at the satellite pictures, I can really see what's coming." Their company has about 15,000 acres under cultivation. Over a typical harvest season from September to December, the daily weather related decisions must be based on the most accurate information available if costly mistakes are to be avoided. The availability of satellite pictures helps reduce the odds in an operation where mistakes are measured in millions of dollars. The estimated savings of the Waialua Sugar Company alone as a result of using satellite data is $1,000,000 per year.

D. Crop Monitoring

The polar orbiting NOAA satellite's Advanced Very High Resolution Radiometer (AVHRR) Channel 1 and 2 data are used by a variety of national and international agencies for crop monitoring purposes. Some of these are:

a. U.S. Department of Agriculture Crop Commodity Assessment Division (CCAD) uses AVHRR data to monitor yields internationally including Russia, Australia, Argentina, India and Canada. Crop yields in these nations can have a direct impact on commodity prices in the United States. CCAD has been receiving about five AVHRR tapes daily from NOAA since May 1981. These are sent via air express from NOAA/NESDIS headquarters in Suitland, MD, to the Johnson Space Center (JSC) in Houston, TX. The data generally arrive at JSC for operational analysis by CCAD within 48 hours of a satellite overpass. Annual cost of the tapes to CCAD is as follows: 5 tapes daily x $72 per tape x 365 per year = $131,400 (annual cost). CCAD receives Landsat data for these same areas via the JSC-GSFC satellite (DOMSAT) link. In the past, Landsat-3 data arrived 6 weeks after overpass, but CCAD's only costs were for time on the link. In 1983, CCAD will receive the Landsat 4 data within 48 hours, but at a cost of almost $1000 per scene. Prior to 1981, CCAD used 15,000 Landsat scenes yearly. Users will obviously have

to balance their budgetary resources, need for geographic coverage and need for the highest resolution data available to obtain the proper Landsat MSS vs. NOAA AVHRR mix.

b. The United Nation's Food and Agriculture Organization (FAO) uses NOAA AVHRR data in several projects some of which are listed below:

- The Sud area in Sudan - monitor agriculture development activities in an area which experiences yearly flooding from the Nile.
- Kenya - country-wide agricultural land use assessment
- Zambia and Botswana - monitor grazing lands and large scale land use changes.
- Lake Chad area (Niger) - monitor agricultural activity surrounding the lake

4. Search and Rescue Operations

Satellite pictures provided by the National Environmental Satellite, Data, and Information Service (NESDIS) assist in search and rescue (SAR) planning throughout the United States inland SAR area. The satellite data are coordinated through the Air Force Rescue and Coordination Center (ARFCC) located at Scott Air Force Base, Illinois. The USAF Aerospace Rescue and Recovery Service provides coordination of air searches throughout the United States. When an aircraft is overdue, the AFRCC must obtain the routing of the aircraft, determine if weather might be a factor, check on the missing pilot's qualifications and have a knowledge of the performance capabilities of the missing aircraft.

Most search and rescue missions conducted over the enroute phase of flight have shown that missing general aviation aircraft encountered unexpected weather along their route. Pilots who obtained weather briefings prior to departure in which good VFR flight conditions were forecast, encountered narrow bands of unreported weather which can be seen on satellite imagery. If an aircraft is reported missing, areas of severe weather can be located with satellite imagery showing conditions at the time the pilot was in distress. These pictures assist in determining if certain preferred mountain routes were open or blocked by hazardous weather. The height of the cloud tops can be determined to see if the missing pilot could fly over the storm system or was faced with staying at lower altitudes and trying to get through the weather.

The statistics for missing general aviation aircraft that were lost on the enroute phase of flight over three years are discussed below. These are incidents in which the USAF Aerospace Rescue and Recovery Service (AARS) responded with search and rescue service. During the period 1975 through 1977, a total of 747 aircraft were lost. A total of 1,679 persons were aboard these aircraft of which 1,008 were killed and 671 survived. Based on the analysis of satellite imagery of the crash sites, the AARS and the California Wing of the Civil Air Patrol (CAP) believe that weather was a factor in more than 85% of these aircraft accidents. A ten-year study of aircraft accidents by the National Transportation Safety Board (NTSB) for the period 1964-1974 without analysis of satellite imagery, indicated that weather was a factor in only 25% of the accidents.

The California Wing of the CAP began utilizing satellite photos obtained from the NOAA Satellite Field Services Station in San Francisco for SAR in October 1974. By mid-1975, it was apparent that satellite data were a new timesaving aid in locating missing aircraft. During this test period, 58 search missions were conducted and only two searches exceeded 48 hours. During the previous year, 46 search missions were conducted and CAP pilots averaged more than a week searching for the crash sites. Search missions of 24 to 48 hours are now common as opposed to several days to two weeks without satellite data .

During the period 1975 through 1977, a reduction of 32% in total SAR flying hours was realized by the USAF ARRS and the CAP. However, at the same time, the number of SAR missions actually increased by 14%. Following the introduction of satellite data to SAR operations, for the first time in the history of rescue service, the number of flying hours actually decreased. The following table lists the number of CAP missions, hours flown, and average hours per mission for a seven year period.

Civil Air Patrol Mission Summary (1971-1977)

Year	Number of Missions	Hours Flown	Average Hours per Mission
1971	389	30909	79.5
1972	348	27391	78.7
1973	429	27284	63.6
1974	460	21773	47.3
1975	694	24500	35.3
1976	817	17064	21.6
1977	896	16004	17.9

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Satellite support of search and rescue was introduced in 1974, tested in 1975, and has been used extensively since 1976. The mission summary table above shows a marked decrease in average hours flown per mission. Between 1974, immediately before the launch of the SMS satellite, and 1977, the average number of hours flown per search and rescue mission has decreased by 62%. With the average cost of $36 per hour for fuel, oil and maintenance (CAP manpower is entirely voluntary), these reductions result in an annual savings of $344,000 for CAP search and rescue operations. USAF ARRS C-130 SAR mission hours were reduced by 7000 hours for both 1976 and 1977. At $995 per hour, this results in an annual savings of $6,965,000 for C-130 time alone. Thus satellite data, available on an operational basis, has annually saved several million dollars in tangible benefits and has produced untold intangible benefits in reductions of human suffering and death through the faster location of missing aircraft.

5. Ice Monitoring

Shipping operations in the Arctic, Great Lakes, and St. Lawrence Seaway are obviously greatly affected by sea, lake, and river ice. The National Environmental Satellite, Data, and Information Service provides support during the ice season to the U.S. Coast Guard International Ice Patrol. The satellite ice analyses are also extremely valuable to ice reconnaissance aircraft in Canada as an aid in pre-flight planning and in locating areas of improved visibility. This has resulted in increased efficiency in the visual reconnaissance missions producing a savings of about 1500 aircraft flight hours and related cost reductions of about $5,000,000 annually.

The Canadian Centre for Remote Sensing (CCRS), Department of Energy, Mines and Resources has shown that imagery indicating the presence and extent of sea ice has been very useful and cost effective to geophysical survey ships engaged in seismic surveying off the north coast of Canada in the Arctic Ocean. AVHRR images are routinely received by the Atmospheric Environment Services Receiving Station at Downsview, Ontario.

Seismic operations for oil and gas exploration in the Bering Sea, Norton Sound, Chukchi and Beaufort Seas have relied heavily on satellite observations. Because of the competitive nature of this activity, information is proprietary, but exploratory companies involved indicate that the satellite data are used as a planning tool to lay out cruise tracks that save time and fuel and minimize damage by ice to non-ice reinforced ships and testing equipment. The presence of any floating ice makes seismic sounding impossible. In one instance, an area scheduled for survey was found to have free floating ice fragments. Advice was sought by a geophysical survey ship from the CCRS which redirected the ship to a nearby area (100 n.mi. away) where ice-free conditions were

interpreted from the daily satellite imagery. As a result, the ship was able to acquire twice the amount of data normally gathered. In this instance, the single image saved $250,000.

In another other example, the ARCO Oil Company used NOAA satellite imagery in 1979 to monitor ice conditions near Alaska. ARCO was using a drilling ship designed for use in the Gulf of Mexico for exploratory ice drilling in the lower Cook Inlet. By using the satellite data, ARCO was able to save $45,000 in insurance premiums on this project. A more recent example of the use of satellite data to monitor ice conditions in support of offshore drilling operations occurred in January 1983. The ARCO Oil Company was using the "Gulf of Mexico" jack-up rig drilling an exploratory well north of Port Heiden in the Aleutians. Extremely cold temperatures and a strong north wind began moving the ice front towards the rig at 25-30 miles per day. NOAA satellite imagery and analyses of the ice were provided daily by the Anchorage SFSS to the Minerals Management Office, U.S. Coast Guard, ARCO and the media. The rig was eventually evacuated and towed to safety based almost entirely upon the real-time analysis of the polar satellite imagery. Sacellite ice observations also play an important role in the Arctic regions for the U.S. Fish and Wildlife Service monitoring of marine mammals' (walrus, whales, seals and polar bears) migration patterns.

In the Great Lakes, satellite imagery is used to find navigable waters for shipping as long as possible into the winter season. The high resolution satellite images show small ice free areas which can be used by ships to continue operations longer than previously possible. It is estimated that the extension of the shipping season by this method results in a cost benefit of $1,000,000 per day for each day extended. Before the use of satellite data, the Great Lakes were closed to shipping for about 2 months each winter. In the winter of 1976-1977 which was exceptionally bad, the Lakes were closed to shipping for only 1 month and during the 1977-1978 winter, they were never completely closed. In this case, however, it is incorrect to attribute all of the savings to satellites alone, since the use of side-looking radar (SLR) on reconnaissance aircraft was introduced in the same time period. Nevertheless, satellites could contribute to annual savings of as much as $30 million.

Satellites are also used to provide early warning of river ice melting and break-up, which could cause ice jams and flooding. Hydrologists require timely information on the progress of river ice break-up during spring thaws. Ice jams often cause severe flooding and threaten hydroelectric plants, bridge piers, and ship navigation. As an example, in 1977, NOAA scientists closely monitored the Ottawa River in Canada using visible images from NOAA's polar orbiting satellites. They were able to view the day-to-day changes in break-up and melting of the ice.

6. Snow Cover Mapping

The use of satellite acquired data for mapping snow cover has proven valuable in water resource planning and flood forecasting. Snow covered area estimates from operational NOAA satellites have proven to be much faster and more economical than conventional aerial surveys. Snow and ice cover a significant portion of the earth's surface. For example:

1. Snow covers 30-50 percent of the land area.

2. Ice covers about 25 percent of the oceans.

3. Glaciers cover about 10 percent of the land area.

4. Permafrost covers 10 percent of the land area.

Frequent observations of the extent and characteristics of snow and ice are needed to assist many industries in their day-to-day operational requirements. Some operational requirements which are especially affected by snow are (1) flood warning systems, (2) municipal and regional water supply management, (3) irrigation systems management, (4) hydroelectric power management, (5) energy requirements, (6) transportation systems operations, and (7) food supply requirements.

For example, satellite snow cover analyses were used in 1976 while a storm was still in progress to determine that it would not be necessary to spill the Verde River reservoir system in Arizona as had been previously planned. Spilling of the reservoirs would have put water into the normally dry Salt River channel above Phoenix which causes road closings and local flooding in the Phoenix metropolitan area and results in the loss of valuable irrigation water. The dollar savings were considerable. In addition, continental snow cover has important climatic impacts on surface and air temperature, radiation balance, soil moisture, cloudiness and precipitation.

Mr. Donald R. Wiesnet, former hydrologist with the National Environmental Satellite, Data, and Information Service, has shown that satellites have made a significant contribution in snow cover mapping where the cost ratio between the satellite and conventional aerial survey is as much as 200 to 1 in favor of the satellite. For example, it takes about 40 hours of flying at $500 per hour to map 20 river basins in the Sierra Nevada mountains. Thus, it costs about $20,000 per aerial mapping operation which is done several times during the winter and spring, funds permitting. When cloud free conditions are available, this job can be accomplished using satellite data in about two man-days at a cost of $200. Thus, annual savings in mapping the Sierra Nevada basins alone could be as much as $1,000,000.

In the mountainous regions of the United States, millions of dollars are spent each year to measure snowpack at fixed locations for forecast purposes. In 1969, a panel of scientists from the National Academy of Sciences states, "The changing extent, surface temperature, thickness, water equivalent, and liquid water content of seasonal snowpack are necessary for engineering design and operation and planning of water projects large and small. In the mountain areas of the United States, millions of dollars are spent each year at fixed locations to measure snowpack for forecast purposes. Improved forecasts are estimated to be worth $10,000,000 to $100,000,000 per year to water users in the western United States alone." Operational environmental satellites can contribute greatly to improved hydrological forecasts.

Seventy percent of the runoff in the western United States is derived from melting snow. In a study funded by the National Science Foundation, it was found that increased cloud seeding in the upper Colorado River basin could result in snowpack augmentation with $12.8 million annual benefits.

NESDIS began operationally producing satellite snowcover maps for 30 selected western U.S. river basins in the spring 1974. The snowcover data are used in river runoff models, dam and reservoir release decisions, and are input to seasonal water supply forecasts to determine how much water is available for irrigation, hydroelectric power generation, municipal consumption, and recreation. About 600 river basin snow maps are produced annually; data are relayed to users via teletype, telecopier or through the mail. Agencies involved as subscribers to this satellite service include the U.S. Forest Service, Soil Conservation Service, Army Corps of Engineers, Bonneville Power Administration, National Weather Service, Bureau of Reclamation, Bureau of Land Management, and the U.S. Geological Survey.

In the late 1970's, the National Aeronautic and Space Administration (NASA) initiated a four year (1975-1979) effort to evaluate the usefulness of satellite snowcover information for water resource managers. The project was identified as the snowmapping Applications Systems Verification Transfer (ASVT) project. Volume VII of the project's final report addressed cost/benefit aspects of the snow study. It was found that:

a) The improvement in runoff prediction due to the addition of satellite information is 6-10%.

b) Benefit models developed for irrigation and hydroenergy uses revealed savings of $36.5 million yearly when satellite snowcover data were supplied for river basins throughout the western United States. The cost of such a satellite snowmapping program was determined to be $505K, thus yielding a benefit/cost ratio of 72:1.

7. Natural Disaster Warning

Environmental satellites have been very effective in providing data for improved natural disaster warnings. It is however, very difficult to correlate lives and dollars saved during a disaster directly to improved forecasts and warnings. NOAA satellites provide environmental data to forecasters and government officials regarding tornadoes, severe thunderstorms, hurricanes, tropical storms, flooding, severe winter storms and other less destructive environmental phenomena. Satellite data are transmitted around-the-clock, 7 days-per-week to the various National Centers for environmental warning including: the National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri; the National Hurricane Center (NHC) in Miami, Florida; the Eastern Pacific Hurricane Center in San Francisco, California; and the Central Pacific Hurricane Center in Honolulu, Hawaii.

A. Hurricane Warning

Satellite imagery is used extensively in monitoring tropical storms and hurricanes. Several years ago, aircraft reconnaissance was the primary method of finding and tracking dangerous tropical storms in the oceans. Increasing costs of petroleum, maintenance and manpower have caused a drastic cutback in tropical storm reconnaissance by the U.S. Air Force and NOAA. The satellite observations have practically replaced all storm reconnaissance except when a hurricane is approaching land. The cost of aerial reconnaissance is about $2,500 per hour and the average mission requires at least 10 hours. Thus, there is a potential savings of $25,000 per flight for every reconnaissance flight avoided by the use of satellite data. In addition, the satellite imagery has enabled the aircraft storm reconnaissance to be more efficient and cost effective in plotting flight tracks for data gathering due to improved navigational information about the location of tropical cyclones.

Since the inauguration of the operational satellite system, no tropical storm goes undetected, even in the most remote areas of the world. The GOES-E spacecraft acquires an image every 30 minutes around-the-clock of the North Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico providing excellent tropical storm detection and monitoring capabilities. Hurricane reconnaissance aircraft no longer have to fly random search patterns over the vast tropical oceans to locate storms which may be developing there. Estimated savings from using satellite storm detection and monitoring in mid-ocean in place of expensive aircraft reconnaissance are about $1,800,000 annually.

The information listed below illustrates the magnitude of hurricane destruction in terms of dollars and fatalities.

Hurricane Fatalities and Damage (1900 - 1982)

Year(Period)	U.S. Fatalities	U.S. Damage ($ Millions)	
1900-1904	6000	N/A	
1905-1909	2200	N/A	
1910-1914	100	N/A	
1915-1919	983	541	
1920-1924	9	15	
1925-1929	2114	357	
1930-1934	80	164	adjusted to
1935-1939	1026	850	1957-1959
1940-1944	149	495	construction
1945-1949	67	480	costs
1950-1954	217	918	
1955-1959	675	1331	
1960-1964	173	1156	
1965	75	1420	
1966	54	15	
1967	16	200	
1968	0	10	
1969	364	1455	
1970	11	454	
1971	14	213	unadjusted
1972	121	3097	annual
1973	6	18	cost
1974	1	150	
1975	55	550	
1976	9	100	
1977	0	0	
1978	36	20	
1979	22	3050	
1980	3	300	
1981	0	25	
1982	1	280+*	

*Hurricane Iwa damage assessment was not completed at the time this paper was written. Hawaii had not been struck by a hurricane in 23 years.

The most damaging individual hurricanes by name and year are listed below:

Costliest United States Hurricanes of Record

Name	Year	U.S.Damage ($)
Frederic	1979	$2,300,000,000
Agnes	1972	2,100,000,000
Camille	1969	1,420,700,000
Betsy	1965	1,420,500,000
Diane	1955	831,700,000
Eloise	1975	550,000,000*
Carol	1954	461,000,000
Celia	1970	453,000,000
Carla	1961	408,000,000
Donna	1960	387,000,000
David	1979	320,000,000

*Includes $60,000,000 in Puerto Rico

The damage estimate of $2.3 billion makes Hurricane Frederic the costliest hurricane ever to hit the United States, exceeding the $2.1 billion cost estimated for Hurricane Agnes in 1972. Five deaths were attributed directly to Hurricane Frederic in the United States, only one of which occurred along the coastal region when a person was swept off a boat near Pensacola, Florida. The insurance industry estimated insured losses of $750 million for Hurricane Frederic. Approximately 250,000 persons were evacuated in advance of Frederic.

A 1975 NOAA Technical Memorandum entitled, A Statistical Study of Tropical Cyclone Positioning Errors with Economic Applications by C.J. Neumann noted that until 197[illegible], the initial position error for storms within 500 n.mi. of the coast averaged 22 n.mi., and landfall forecasts were made from distances no more than 300n.mi. A positioning error is defined as the difference between the forecaster's assumed initial position of a storm and the actual position as determined from a postanalysis.

The issuance of hurricane warnings along a portion of the United States coastline is generally accomplished 18 to 24 hours prior to the expected arrival of the storm at the coast. This particular time interval has been found to be an optimized trade-off between the desire to provide maximum warning lead time and the ability to keep the size of the warning area within reasonable limits. With such a lead time, the length of the warning zone averages nearly 300 n.mi. Inasmuch as the swath of damaging winds is generally less than 100 n.mi., the public must expect a minimum overwarning area of about 200 n.mi.

The study includes an economic analysis of potential changes in the size of hurricane warning areas. It is estimated that protection costs (including losses due to temporarily curtailed production) for a typical 300 n.mi. Gulf of Mexico coastal hurricane warning zone total $25.1 million. A 10 n.mi. increase in positioning error will increase this economic loss by about $5 million per storm. A 10 n.mi. decrease in positioning error will decrease protection costs by about $2.75 million per storm. Since an average of about two hurricanes annually move inland on the continental U.S., using the above figures, $50 million is the average annual cost of protection. As a conservative estimate, a reduction of only 5% in the coastal warning area would mean an average annual savings of about $2,500,000 per year. Satellite observations play a major role in keeping the warning area to a minimum.

B. Global Tropical Storm Monitoring

NOAA polar orbiting satellites are used to monitor tropical storms worldwide in addition to those near or endangering the United States. The following table lists the number of named tropical cyclones monitored and tracked by NOAA satellites in three remote ocean areas of the world.

Satellite Monitored Named Tropical Cyclones

Year	West Pacific Ocean	South Pacific Ocean	Indian Ocean
1974	38	12	26
1975	27	8	33
1976	27	10	27
1977	21	10	23
1978	27	7	23
1979	27	6	20
1980	27	8	20
1981	28	12	19
1982	27	9	21

When these storms are detected and tracked by polar satellite, a Satellite Weather Bulletin is sent directly to the meteorological agency of the countries which could be affected by the storm. These bulletins are transmitted daily throughout the life of the tropical storm which averages 8-10 days. In the highly populated countries of southeast Asia, this satellite tropical storm warning service could save many lives if the capabilities to disseminate the warning to the general public were available. Unfortunately, in many cases, the populace does not receive the warnings due to the lack of adequate communications facilities and the death toll has not reflected the availability of these timely warnings.

C. Severe Thunderstorm and Tornado Warning

Satellite imagery is a primary data source for the National Severe Storm Forecasting Center (NSSFC) in Kansas City which has severe thunderstorm and tornado forecasting responsibility for the continental United States. In 1972, the NESDIS established a Satellite Field Service Station (SFSS) collocated with the NSSFC. The Kansas City SFSS has been instrumental in developing new techniques in applying satellite imagery to severe storm forecasting. The use of high resolution GOES visible and enhanced infrared imagery taken at frequent intervals (as often as every 15 minutes) has been extremely useful in monitoring the development of severe thunderstorms. This satellite capability has enabled NSSFC forecasters to pinpoint areas with a high probability of a tornado so as to reduce the area of warning. By reducing the area of warning, the "cry-WOLF!" attitude that sometimes exists toward tornado alerts will be lessened. The satellite has been instrumental in accurately defining the tornado watch areas which are provided to the news media and NWS forecast offices.

The following table lists the fatalities and property loss statistics for the period, 1972 through 1982.

TORNADO SUMMARY (1972-1982)
Property Loss Frequency*

Year	Number of Tornadoes	Fatalities	Category 5	Category 6	Category 7 and over
1972	741	27	100	28	1
1973	1102	87	219	67	9
1974	947	361	166	82	25
1975	920	60	189	31	11
1976	835	44	145	41	5
1977	852	43	173	40	6
1978	788	53	153	53	6
1979	852	84	169	62	11
1980	866	28	205	79	13
1981	782	24	144	43	12
1982	1028	64	N/A	N/A	N/A

*Number of times property losses were reported in storm damage Categories 5, 6, 7 and over.

Property Loss Category Definitions

Category 5	$50,000 - $500,000
Category 6	$500,000 - $5 million
Category 7	$5 million - $50 million
Category 8	$50 million - $500 million
Category 9	$500 million and over

The above losses are based on estimated values at the time of occurence.

As shown in the table above, the cost of damage has risen significantly in recent years due to more populated areas being hit by tornadoes and increased building costs due to inflation. Because tornadoes and severe thunderstorms are relatively small scale and short lived, it is difficult to prepare to protect property in a manner similar to that which is done with the larger scale and slower moving hurricanes. It is currently impossible to predict the exact time and locations these severe storms will arrive, but satellite images provide an indication of the development of the type of meteorological situations in which these storms occur. Unfortunately, satellite observations of tornadoes and severe thunderstorms can do little to aid in reducing the amount of property damage sustained. It is significant, however, that there has been a notable reduction in the average number of deaths since 1975.

Beginning in 1975, GOES data has been a significant and heavily used input to the NSSFC. It seems clear that there is a correlation between the lower number of lives lost since 1975 and the introduction of operational geostationary satellite data into the severe storm forecasting and warning process. Even excluding the April 3rd calamity of 1974, an average of 84 fatalities per year occurred between 1968 and 1974. The average number of deaths since satellite data has been extensively utilized is 50 fatalities per year.

The New Orleans SFSS plays an important role in reducing the element of surprise of severe weather sweeping in from the Gulf of Mexico and overtaking mariners, offshore oil workers and coastal residents. During this century alone, 21 hurricanes have come ashore from the Gulf killing hundreds of persons and causing billions of dollars in damage. In addition, scores of tropical storms and winter-time cyclones have hit the Gulf coast areas. Although not as severe as hurricanes, these storms cause extensive damage and threaten the lives of those individuals who use the Gulf for their livelihood and recreation.

With the advent of the energy crisis, emphasis has been placed on offshore oil drilling and production activity. The magnitude of this effort is reflected in the following statistics. There are 1,249 production platforms with heliports, approximately 240

drilling rigs on location, and 28,000 individuals working offshore. To support this vast and complex industry, approximately 700 helicopters (flying an average of 25,000 hours per month) transport 150,000 passengers each month from bases located along the Texas and Lousiana Gulf coast.

The New Orleans SFSS focuses on small-scale meteorological events in an area extending from 90 miles onshore to 200 miles offshore. Special attention is given to the thunderstorms and squall lines which develop rapidly throughout the Gulf with little advance warning. When these storms are detected, the SFSS issues advisories to National Weather Service Offices and other government agencies along the Gulf coast.

D. Flood Warning

Satellite data also have been valuable in providing early warning for floods. An example is the September 13, 1977 flood disaster in Kansas City. Information provided by the NESDIS SFSS in Kansas City to National Weather Service Forecast units prior to and during the Kansas City flood was timely and accurate. The early recognition of the precipitation boundary which had been left by the previous night's thunderstorm activity in northern Missouri identified a meteorological mechanism which had potential for initiating new thunderstorm development over an area where the ground was already saturated. This satellite information, when incorporated with other data, contributed to the NWS decision to issue a local forecast early in the day for heavy rain. Later satellite data provided information which was instrumental in the issuance of a severe thunderstorm watch which included the Kansas City metropolitan area. The satellite evaluation gave new information concerning the southward shift of the axis of thunderstorm development, and coupled with supporting evidence from the NWS radar, suggested the potential for heavy rain in the Kansas City area.

An example of satellite contributions to international flood warnings occurred in August of 1977 when United States satellite assessments of snowpack were used as an indicator of flood potential in Pakistan. NOAA-5 VHRR coverage was especially programmed to include the Himalaya Mountains. Two large river basins in the Himalayas were monitored: the Indus River above Besham (162,100 km^2) and the Kobal River above Nowshera (88,600 km^2). A late snow melt in the Himalayas could have greatly increased the potential for flooding in Pakistan. Percent snowcover as derived from the satellite was compared with historical data and transmitted to the Pakistani Ambassador in Washington, D.C.

Satellite data is very beneficial in flash flood forecasting. During the period October 12-13, 1981 excessive rainfall occurred over Texas and Oklahoma. The primary ingredient for this episode was a dying tropical storm (Norma) which was moving out of Mexico.

Numerical forecast models, due to the scarcity of data over Mexico, were unable to forecast its movement. The first hint of this feature moving toward Texas came from satellite derived data. This information prompted the issuance of twenty Flash Flood Watches in various parts of Texas. As the system moved into Texas, triggering copious rains, Quantitative Precipitation Estimates based on satellite images were provided to numerous NWS offices. There were four major floods during 1982. Flooding in Fort Wayne, Indiana, New England, Louisiana and the central Mississippi valley claimed 150 lives and caused damage in excess of $2 billion.

8. Large Scale Weather Forecasting

NOAA operational environmental satellites contribute greatly to the National Weather Service's National Meteorological Center (NMC), the central weather analysis and prediction facility for the United States. At NMC, which is also a World Meteorological Center, observations from all over the globe including satellite data are collected, processed by computer, and used to produce maps of existing and predicted weather conditions. In a 24-hour period, the NMC receives about 42,000 approximately 50,000 satellite observations. Maximum benefits from satellite data are realized when this information is effectively used to bridge the gap in time and space between conventional meteorological observations. A synthesis of all types of meteorological data such as satellite, surface, upper air, radar, etc., results in a more complete and accurate understanding of atmospheric processes.

Dr. Robert M. White, former Administrator of NOAA, discussed the role of satellite data in large scale weather applications in an article in The Military Engineer (July-August 1973) entitled Environmental Satellites - A Progress Report. In this article, he wrote the following:

"The World Meteorological Center, Washington, D.C. (the other World Centers are in Moscow and Melbourne) uses photographs, temperature soundings, and wind measurements acquired by satellite to improve the accuracy of large scale weather analyses and forecast weather charts. These charts are communicated by facsimile circuits to civil and military weather stations in the United States and become part of the guidance material given to field stations for use in weather forecasting. Air Force and Navy weather centrals receive both direct and processed data for use in similar ways. Analysis centers, which provide special services to agricultural, hydrological, engineering, maritime, and other interests, use satellite data routinely in the preparation of their products. Several factors make satellite data unique in comparison with data acquired from other sources. A major characteristic is that, because of its vantage point above the atmosphere and its broad field of view, the satellite can provide information regularly for vast areas of the globe where data from other more conventional

sources are sparse or unobtainable. This coverage of the large data gaps over oceans and remote land areas is one of the basic and most important contributions of satellites to improved weather forecasts. Also important is the immediacy of data transmitted directly from satellites to ground stations. Such data frequently are received and put into use some hours before routine data are received through normal communications channels. The third characteristic is the broad view of earth and atmospheric features that can be obtained only from satellite altitude. Large-scale weather systems can be seen in a single view, whereas the definition of atmospheric or sea surface conditions obtained from aircraft or groundbased observation is incomplete."

The environmental satellite is an excellent global observational platform and the United States freely contributes data from its satellites to the world meteorological community. Satellite data is an important part of the World Weather Watch Program of the United Nations' World Meteorological Organization. The direct readout systems (APT and HRPT) from the polar orbiting spacecraft and the WEFAX transmissions from the geostationary spacecraft are used by more than 123 countries around the world.

Thus, environmental satellites contribute significantly to large scale weather observation and forecasting. Deriving the actual cost benefits of such services is extremely difficult, if not an impossible task. This is because the only way of obtaining these benefits would be to compare the cost of information obtained via satellite with what it would cost to acquire comparable data via conventional means (e.g. surface observations, radiosonde, radar and meteorological buoys). Not only would the acquisition costs be prohibitive, but it would be physically impossible to obtain this large amount of diverse data in a timely manner. The value of satellite acquired observations to global scale forecasting is certainly several millions of dollars annually.

9. Miscellaneous Activities

There have been many uses of environmental satellite data some of which are significant and others which have no measurable economic benefit at present, but may have in the future. This section briefly discusses some of these activities related to the utilization of environmental satellite data.

A. Airline Fuel Savings

The NASA Lewis Research Center completed a 20 month study in 1981 regarding the value of improved upper air wind and temperature forecasts to the worldwide commercial airline industry. This study was discussed in a paper entitled Airline Flight Planning - The Weather Connection by Robert Steinberg in April 1981.

In his paper, Mr. Steinberg reviews the meteorological basis for the present method of airline flight planning and analyzes its impact on current flight operations. He suggests a new approach for developing a weather base for flight planning which has the potential of providing fuel savings of 2 or 3 percent on long distance flights.

Mr. Steinberg suggests that a meteorologist, using man-computer interactive techniques, could develop an accurate upper air nowcast (3-12 hours) using the NWS synoptic numerical forecast, satellite data, rawinsonde and pilot reports. Satellite data is the most timely and also provides information on the location of jet streams, which is very important. This nowcast would provide the basis for automated flight planning by the airline.

Mr. Steinberg estimates that an interactive system with satellite data input to provide upper air tuned forecasts, including manpower for a 24 hour operation would cost about $600,000 per year after a one time capital investment for equipment of about $1,000,000. An international carrier with a present fuel bill of one billion dollars could expect to save at least $20 million per year on trip fuel alone. When one considers the potential for optimizing reserve fuel requirements, the savings could even be considerably higher.

B. Game Bird Management

The Office of Migratory Bird Management of the U.S. Fish and Wildlife Service has used NOAA polar-orbiting VHRR pictures to help determine the reproductive success of several species of arctic nesting geese. The Wildlife Service is responsible for annually adjusting hunting regulations to conform with the estimated population of particular species of waterfowl. The waterfowl managers must know well before the hunting season what the supply of game birds will be, otherwise their existence could be threatened by over-harvesting.

The most important factors affecting the reproductive success of arctic nesting geese is the timely disappearance of snow, ice, and the availability of melt water to allow for the production and rearing of young. Late seasons or adverse weather conditions can result in the geese not nesting, reduced brood sizes, or failure to renest. Any of these adversely affects the population. Waterfowl managers, using NOAA's polar orbiting satellites, can monitor habitat snow and ice conditions in the remote arctic nesting areas in a timely and economical manner. The satellites provide visual and infrared images twice daily to help identify areas of catastrophic or outstanding goose production, permitting the wildlife service to establish appropriate hunting regulations.

C. Dust Storm Monitoring

Both the geostationary (GOES) spacecraft and the polar orbiting (NOAA) spacecraft have been used to monitor the development and dissemination of dust storms in the Plains States. For example, in February 1977, these operational satellites detected dust clouds originating in New Mexico and Colorado and tracked them across Kansas, Oklahoma, Mississippi, Alabama and Georgia out into the Atlantic Ocean. The major dust storm was considered among the worst since the "Dust Bowl" days of the 1930's.

Monitoring the development and movement of dust storms is important to the aviation industry, soil erosion and agriculture experts, scientists conducting solar energy research, pollution monitoring specialists, etc. Satellites can be used effectively by meteorologists to monitor major dust storms.

D. Locust Plague Control

Agricultural crops and rangeland resources estimated to be worth 30 billion dollars over some 30 million square kilometers in 60 countries with more than a fifth of the world's population are prone to the ravages by the Desert Locust, Schistocera gregaria. The primary factors which influence the growth and movement of the locust are the temperature and moisture content of the air and ground and the standing crop. These factors can be measured using NOAA environmental satellites and Landsat satellites. NOAA polar-orbiting satellite images have been used by the United Nations Food and Agriculture Organization (FAO) to monitor areas of probable rainfall in northern Africa countries such as Algeria, Somalia, India, and Pakistan. The NOAA satellite images are examined in detail with Landsat images of these areas, enabling U.N.FAO scientists to locate areas of emergent vegetation which is essential for desert locust development. The location coordinates of potentially dangerous areas are relayed to locust control teams in the countries involved. These teams then examine the area and determine if insecticide spraying is necessary to inhibit the development of migratory swarms.

Building further on the results obtained during the Desert Locust/Remote Sensing Pilot Project, carried out by FAO in Northwest Africa in 1976/77, techniques were developed and initially tested for quantitative rainfall monitoring over large areas using environmental satellite data, e.g., Meteosat and TIROS-N/NOAA, and vegetation biomass activity detection and monitoring with Landsat digital data. Vegetation monitoring for the entire desert locust region with Landsat 80 meter-resolution data (MSS Bands 5 (visible) and 7 (near infrared)) requires the processing of huge amounts of data at an extremely high cost. Analysis has shown that Landsat data often has excess resolution for FAO purposes and can be reduced by a factor of 35 and still used effectively.

With the launch of TIROS-N in October 1978 and NOAA-6 in June 1979, 5-channel AVHRR data (including the near infrared) at a resolution of 1.1 Km became operationally available for the first time. Previous NOAA polar orbiting satellites (the ITOS series) had sensors that imaged only in the visible and thermal infrared regions of the spectrum. FAO began exploring the use of AVHRR data in desert locust studies in the summer of 1980 with promising results. Locust breeding grounds in southern Algeria were successfully identified for the first time on AVHRR data of August 31 and September 10, 1981. The data were analyzed on the NASA/GSFC H.P.1000 interactive system. Ground confirmation was supplied through FAO headquarters in Rome.

E. Volcano Monitoring

Ash spewed out from erupting volcanos may remain in the atmosphere for many months posing a threat to commercial aircraft. The ash and dust may also affect the earth's radiation balance and surface temperature and in turn, crop and vegetation growth. The five channel AVHRR data have been used in recent studies to determine height of volcano plumes, plume dispersal, plume composition as well as to map the extent of lava flows and the distribution of volcanic ash and dust on the ground. Information gleaned from the satellite data is then passed to the Smithsonian Institute for inclusion in the SEAN (Scientific Event Alert Network) Bulletin published each month in order to pass needed information to scientists and government officials.

The AVHRR satellite data are analyzed on the H.P.1000 interactive system at the NASA/Goddard Space Flight Center. Information on the volcanic plume height is obtained by reducing the thermal data in channels 4 and 5. The extent of the lava flow can be mapped (while the lava is still hot) by using channel 3. The distribution and amount of dust covering the regional vegetation can be inferred using channels 1 and 2. The following volcanos have been studied extensively by NOAA/NESDIS during the past two years.

Location	Volcano	Dates
Mexico	El Chichon	March 29-April 4, 1982
Java	Galunggung	June 24-July 15, 1982
Soviet Union	Alaid	April 28-May 1, 1981
Iceland	Krafla	February 4, 1981
Iceland	Hekla	April 1981
U.S.A.	Mt. St. Helens	May 18, 1980

A team from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Western Australian Institute of Technology have developed a method of tracking volcanic clouds. The Australian team recognized that the volcanic ash would contain a large amount of silica that the infrared radiation band would

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detect. When the clouds begin to disperse, they consist of particles only a few microns across and they attain very high altitudes where they pose a threat to jet aircraft. The ash also merges with other clouds and becomes undetectable in the visible spectrum. The silicates in the ash provide a thermal emission pattern different from other clouds.

F. Metropolitan Planning

The heat emitted from metropolitan areas is measured by high-resolution infrared sensors aboard NOAA's polar-orbiting satellies. The sensing of urban "heat-islands" by environmental satellites is used by metropolitan planners to monitor population growth and industrial development as it occurs. Planners are able to monitor the urban growth by comparing greatly enlarged computer-enhanced satellite images with urban census maps. The satellite imagery supplements and in certain cases may be more cost effective than aerial photographs as a tool in determining the amount and direction of growth of a metropolitan area and for delineating boundaries for future census surveys.

The pattern of a city's heat can be quantified from satellite measurements and monitored annually or on a season by season basis. Even small urban areas can produce noticeable thermal anomalies or heat islands when compared to their surrounding rural environment. A NOAA-5 image of New Hampshire, Massachusetts, and Rhode Island acquired on May 23, 1978 was digitally enhanced by NOAA scientists to study urban heat islands. A total of 17 heat islands were detected ranging from Norwood, Mass. (pop. 32,000) to Boston, Mass. (pop. 625,000).

G. Hydroelectric Power Production

Temperature changes of 1°C or more at customer locations are reflected in electric power demand variations at the servicing hydroelectric facility within four to eight hours. The hydroelectric operator must regulate water flow or bring thermal power units on-line to compensate for these demand variations. Because it requires about four hours to make major water flow adjustments or to add thermal power, large hydroelectric operators invest substantial amounts in establishing well instrumented surface observation networks (temperature, wind, humidity, and precipitation) over their service regions. Observed data are used as the basis for specific area forecasts by the meteorologists supporting the hydroelectric operator.

In 1973, a major hydroelectric operator, the Tennessee Valley Authority, investigated the potential benefit of using satellite data every one or two hours to increase the density of surface temperature observations in order to improve the accuracy of their four to eight hour forecasts. It was concluded that operational efficiencies could be achieved that would result in savings "in excess of 1% of operating costs."

H. Forest Fire Prevention and Detection

The National Weather Service maintains Fire Weather Offices (FWO's) at 17 locations in the western United States: Billings, MT; Boise, ID; Wenatchee, WA; Eureka, CA; Fresno, CA; Los Angeles, CA; Medford, OR; Missoula, MT; Olympia, WA; Pendleton, OR; Portland, OR; Phoenix, AZ; Redding, CA; Reno, NV; Sacramento, CA; Salt Lake City, UT; and Salem, OR. The "official" fire weather season varies by FWO district, but can begin as early as April 1 and end as late as November 15. The FWO's release a daily Fire Load Index (defined on a scale from 1 to 100) for regions throughout the western United States. The higher the index number, the greater the number of manhours needed to contain a fire. With millions of acres to be monitored in the western region and limited resources to accomplish the task, the fire load index serves as the most important tool in determining how these resources will be distributed over the next day, week or even month. Poor weather forecasts can mean thousands of dollars lost when a misrepresentative Fire Load Index is distributed.

The NOAA Satellite Field Services Station (SFSS) in San Francisco, California, releases a daily Fire Weather Satellite Interpretation Message (SIM) to aid the FWO in deriving the proper Fire Load Index. The SIM's include information on rapidly developing thunderstorms, surface wind speed and direction, precipitation duration and type (layered or convective), cloud cover, variations in temperature and humidity, extent of surface inversions and amount of solar insolation.

Also of interest to fire weather forecasters is measuring the changes in plant biomass or chlorophyll density in forest plant life and cultivated fields. The plant biomass is directly related to its moisture level and thus to its susceptibility to burning. The Bureau of Land Management (BLM) and the EROS Data Center (EDC) are initiating a program to utilize NOAA AVHRR channels 1 and 2 data to determine fuel loading conditions in wildfire hazard areas. The AVHRR data are analyzed to make estimates of standing green biomass loading within previously Landsat-mapped wildfire fuel types. These estimates (high, medium, low) shall then be incorporated as part of the BLM Initial Attack Wildfire System data base. Initial spring 1982 test areas were located in southeastern Oregon, northwestern Arizona, and the Fairbanks region of Alaska. If the experiment is successful, this technique will be used operationally in fuel loading models beginning in 1984 for the entire western United States and Alaska.

A final application of NOAA AVHRR data is to monitor the actual outbreak of fires. The third channel on the AVHRR (3.5-3.9 um) is extremely sensitive to high heat sources. These data have been used to identify oil flares, mine smelts, factories, power plants, lava flows -- and wild fires. Some of these targets have been found to

occupy an area that is less than 1 percent of the AVHRR pixel size, thus effectively giving "sub-pixel resolution" for high heat sources in this channel. The NOAA San Francisco SFSS ran a test in the summer of 1981 which involved locating "hot spots" on the channel 3 imagery and sending out precise locations to the Fire Weather Offices. As many as 30 fires were spotted on a single day. The overwhelming majority of fires detected on the data proved to be controlled timber or agricultural burns. However, in several cases the satellite data were used to give first notice of a fire. Field verification was supplied by the U.S. Forest Service, timber companies, and in several cases, the local police.

I. Bowhead Whale Monitoring

The NOAA Satellite Field Services Station (SFSS) in Anchorage, Alaska, supports several agencies with respect to the annual bowhead whale migration. Direct briefings and blowups of polar satellite visible imagery of the area from St. Lawrence Island to Prudhoe Bay are provided to National Marine Fisheries Service. Polar satellite imagery of the coastal sea ice is provided to the Bureau of Land Management Outer Continental Shelf Program. The imagery is used to determine where aircraft observers should fly to count and observe the whales. In addition, ice imagery is supplied to the nine Eskimo Whaling Commissioners of the Alaska Eskimo Whaling Commission who use the imagery as a management tool.

J. Water Quality Monitoring

The effectiveness of NOAA geostationary satellites in water quality monitoring was demonstrated in a recent study of Pyramid Lake. The lake, located northeast of Reno, Nevada, is the largest desert water body in North America with a surface area of 440 sq. km and a mean depth of 40 meters. During the summer of 1978 and 1980, the lake experienced massive precipitations of calcium carbonate (whitings). In each case the lake surface became entirely covered with calcium carbonate within two weeks of the onset of whiting, and it would take several months to regain its normal appearance. GOES data were used daily to map the entire whiting sequence: the growth, distribution pattern, intensity and finally cessation of the phenomenon. As more and more water is diverted for agricultural, industrial and municipal use in the western United States, lakes will become increasingly susceptible to such events. The NOAA satellites provide a timely source of data for monitoring such events.

K. Recreational Boating

Satellite data has been used as a major data source to brief sailboat cruising races for several years. The 1982 Newport to Bermuda Yacht Race was postponed 48 hours based on forecasts of a

sub-tropical storm being monitored by NOAA satellites and conventional data. Unfortunately, one of the racers ignored the warnings and sailed on the original starting day. The yacht suffered considerable damage and one crew member was lost at sea in the storm. The satellite-based weather support was responsible for preventing considerable property damage and other loss of life in this particular sailboat race.

III. Summary

The use of operational environmental satellite data is well established in support of weather forecasting, especially severe storm forecasting and warning and large (global) scale forecasting. In addition, operational satellite data are used effectively in support of the following variety of activities:

- Ocean Current Navigation
- Ice Monitoring
- Citrus Industry
- Sugar Cane Industry
- Search and Rescue Operations
- Commercial Fishing Industry
- Agricultural Industry

Thus, operational environmental satellites have established their value and benefit to support many public warning functions and economic activities. To the tangible benefits must be added the intangible value of lives saved by improved natural disaster warnings to the public with respect to hurricanes, tornadoes, severe thunderstorms, and flooding. The advent of environmental satellites is the greatest significant advance in routine environmental monitoring that has been developed in history. The operational environmental satellite has earned its place as an irreplaceable weather and ocean observing tool in contributing towards the saving of lives and property from natural disasters and improving the efficiency of many sectors of our national economy.

The benefits discussed herein are evidence that the operational environmental satellite has earned its place as an irreplaceable weather and ocean observing tool. These satellites are making major contributions towards the saving of lives and property from natural disasters and improving the efficiency of many sectors of our national economy.

The Space Shuttle Focused-Technology Program: Lessons Learned

By PAUL E. FITZGERALD, JR.
Martin Marietta Denver Aerospace, Michoud Div.
and EDWARD A. GABRIS
NASA Office of Aeronautics and Space Technology

As the '60s drew to a close, and even before the flight of Apollo 11, the United States' first manned lunar landing, it became obvious relative to the future of our space programs, that

—1. The U.S. was in space to stay.

—2. The cost of expendable, single-use launch systems could not be sustained.

—3. Technology "existed" to develop a reusable Space Transportation System (STS) that could assure Item 1 and solve the problem posed by single-use systems in Item 2.

With respect to (1), U.S. determination to maintain technological leadership in the world assured the pressing of military, scientific, and commercial advantages of space. With respect to (2), extensive studies of potential space users underscored the wastefulness of expendable launch vehicles.

Regarding (3), most technology for most Shuttle subsystems did exist and had been demonstrated; however, for some systems we could claim *critical* technology only in concept and had not demonstrated it even in laboratory prototype.

In 1969, realizing this situation, NASA chartered the Space Shuttle Technology Steering Committee. It then defined, funded, and managed "focused" programs to demonstrate the utility and readiness of promising technologies. The NASA-led effort involved eight of its field centers and more than 100 industrial organizations. It produced many still valuable lessons. The following recalls the focused-technology program, its management structure, payoff in the Shuttle development, and lessons that may aid, for instance, space-station work.

What *is* a "focused" technology program? Depending on the industrial or governmental organization, the terms "research," "technology," "exploratory development," and "advanced development" would probably have slightly different definitions. These four terms represent a progression of technological development leading to the production phase of hardware and software.

We would also agree on at least two categories of research: "basic" research, the search for new knowledge, and "applied" research, which attempts to find new applications for existing knowledge. Our definition of "technology" involves the application of existing knowledge and thus excludes basic research tasks. For our purposes, we call the effort from 1969-73 in support of the Space Shuttle design simply "technology," recognizing it contained a percentage of all the classes of endeavor from applied research to advanced development.

Most of this "technology" effort resulted in breadboard, brassboard, and prototype hardware and software. *None of the technology funds was spent on production hardware or software actually intended to fly.* In this sense, Shuttle technology funds were used principally to demonstrate technology readiness.

To our definition of the term "technology" we add "focused," to mean work *in direct support of a planned program* (e.g., the Space Shuttle). The definition does not exclude the potential use of the technology in question on other programs, but does depend on the target program as its principal justification. Focused-technology projects usually demonstrate a capability, materials applications, or subsystem operational mode to fill a specific program need. A project may need to determine whether or not the program should be attempted with a given technology in its baseline configuration. Since this often involves funding more than one approach for the same design requirements, a focused-technology program inherently involves efforts which verify that certain advanced technology *should not be used* because of cost, technology, or scheduling risks.

Program Structure: One of NASA's great strengths—one not readily apparent in many government organizations—is its facility to respond rapidly to new program needs, opportunities, or problems with *agency-wide* organizational flexibility, cooperation, and sensitivity.

When the 1969 Space Task Group identified a reusable STS (compatible with the economics of space use in the 1980s and beyond) as a goal and determined that the technology "existed" to build it, there was a critical need to determine how much of that "existence" had to be demonstrated. In some cases, we also had to determine which of several dif-

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ferent emerging technology options should be selected for application to the Shuttle. Major examples: the choice between metallic and non-metallic thermal protection systems, between the emerging aerospike engine design and the high-pressure bell-type engines, and among cost trades for numerous reusable Shuttle configurations. Some of these questions could be answered only by building hardware prototypes and testing them to ensure they could meet the requirements. The job of overseeing this work fell to the Space Shuttle Technology Steering Committee.

This Steering Committee was created by the NASA Administrator in 1969 with the appointment of a chairman from the Office of Aeronautics and Space Technology. The Steering Committee had no budget, no working staff, and if it had a written charter no one ever saw it. Yet, over the next four years, it was responsible for the expenditure of $146 million plus the tasks of nearly 3000 scientists, engineers, and technicians in government and industry. Within this four-year period, the Committee demonstrated critical technologies then candidates for the Space Shuttle baseline concept.

Seven working groups reported to the Space Shuttle Steering Committee: (F-1) Operations, Maintenance & Safety, Integrated Electronics, Structures and Materials, Propulsion, Aerothermodynamics and Configuration Verification, Dynamics and Aeroelasticity, and Biotechnology.

Each of these working groups was chaired by a middle manager from a NASA field center who was not only an expert in his field but also well enough known to be respected by his peers at other NASA centers. The membership of the working groups were selected from NASA field centers, USAF R&D laboratories, and the USAF Space and Missile Systems Organization. Each member was an expert in his technical discipline with sufficient insight into the abilities and interests of his center to know how its resources could best be used in technology-demonstration tasks. (All NASA centers were not represented on all working groups.)

LESSONS LEARNED

- **Government and industry must have clearly understood, well-defined roles.**
- **Industry must be a willing participant in the technology programs.**
- **There should be a free and rapid flow of information among government and industrial groups.**
- **Proper program start and stop criteria increase technology yield and decrease costs.**
- **The best expertise available, independent of the R&T or program interest of the organization, must be used.**
- **Program personnel must be active in the technology demonstrations for efficient technology transfer.**
- **Focused technology can have significantly higher yields than unfocused technology.**
- **Focused technology programs that are properly run are cost-effective.**

Each of these working groups convened several times a year to give the Steering Committee recommendations on—

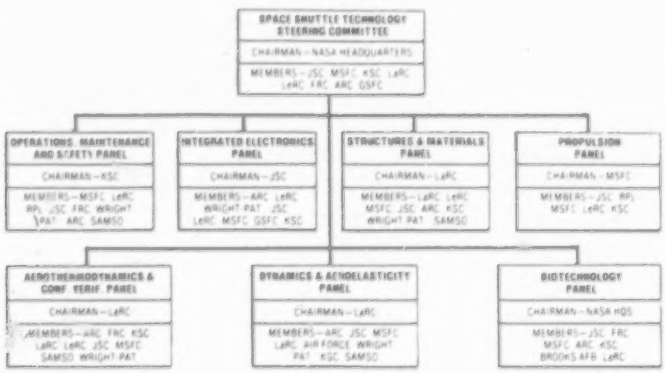
—Technology tasks for the coming fiscal year—including scope, objectives, schedule justification, and priority rationale.

—NASA center best suited to manage each task.

—Funding.

The first factor required extensive study to determine which of the technology candidates required work before full-scale development. The second, which NASA center should be responsible for managing each task was, with few exceptions, deter-

F-1 STRUCTURE AND MEMBERSHIP OF THE STEERING COMMITTEE


SPACE SHUTTLE TECHNOLOGY STEERING COMMITTEE
CHAIRMAN – NASA HEADQUARTERS
MEMBERS – JSC MSFC KSC LaRC LeRC FRC ARC GSFC
OPERATIONS, MAINTENANCE AND SAFETY PANEL
CHAIRMAN – KSC
MEMBERS – MSFC LeRC RPL JSC FRC WRIGHT PAT ARC SAMSO
INTEGRATED ELECTRONICS PANEL
CHAIRMAN – JSC
MEMBERS – ARC LeRC WRIGHT PAT JSC LeRC MSFC GSFC KSC
STRUCTURES & MATERIALS PANEL
CHAIRMAN – LaRC
MEMBERS – LaRC LeRC MSFC JSC ARC KSC WRIGHT PAT SAMSO
PROPULSION PANEL
CHAIRMAN – MSFC
MEMBERS – JSC RPL MSFC LeRC KSC
AEROTHERMODYNAMICS & CONF VERIF PANEL
CHAIRMAN – LaRC
MEMBERS – ARC FRC KSC LaRC LeRC JSC MSFC SAMSO WRIGHT PAT
DYNAMICS & ACROELASTICITY PANEL
CHAIRMAN – LaRC
MEMBERS – ARC JSC MSFC LaRC AIR FORCE WRIGHT PAT KSC SAMSO
BIOTECHNOLOGY PANEL
CHAIRMAN – NASA HDS
MEMBERS – JSC FRC MSFC ARC KSC BROOKS AFB LaRC

T-1 FUNDING BY FISCAL YEAR AND TECHNICAL WORKING GROUP
Figures in millions of dollars.

Working group	FY70	FY71	FY72	FY73	Total
Operations, Maintenance and Safety	1	3	4	1	9
Integrated Electronics	7	9	6	4	26
Structures and Materials	11	22	17	3	53
Propulsion	5	8	7	1	21
Aerothermodynamics and Configuration	4	6	8	4	22
Dynamics and Aeroelasticity	1	3	5	2	11
Biotechnology	1	3	—	—	4
Total	30	54	47	15	146

mined by the working groups. Lastly, the funding estimates were made by the center responsible for the work; the resulting estimates generally proved to be dependable.

Since it had no staff or budget, the Committee and its chairman had to negotiate with existing "fund sources" for the use of *their* funds to do the necessary work. The three fund sources were the Office of Aeronautics and Space Technology (OAST), the Office of Manned Space Flight (OMSF) Advanced Development Office, and the OMSF Space Shuttle Office. The basic charters of these three NASA funding sources placed constraints on the use of congressionally-approved funds. The OAST divisions were committed to funding tasks toward the applied research end of the R&D spectrum; the OMSF Advanced Development Office lay in the middle of that spectrum; and the Shuttle Office leaned toward the developmental end. Within these constraints, the sources made the following allocations (millions of dollars):

Source	FY70	FY71	FY72	FY73	Total
OAST	21	35	31	12	99
OMSF/AD	7	8	6	3	24
OMSF/SSPO	2	11	10	0	23
Total	30	54	47	15	146

With no additional R&D budget allowance during the period 1969-73, NASA "focused" $146 million to ensure that the technology and the Space Shuttle would exist. Individual tasks which made up this focused effort fell into two broad categories:

1. Ongoing work directed specifically to a Shuttle application.

2. New work (not in the NASA R&D program), begun specifically for Shuttle application.

Ongoing work in 1969 (which did not have a critical Shuttle application) was often deferred so that the Shuttle-critical effort could be conducted.

An overview of funding allocations by technical working group, (T-1) gives insight into the weighting and spread of critical technologies by specific discipline.

The totals show that biotechnology was not a major technology concern; operations, maintenance and safety, and dynamics and aeroelasticity required more attention; integrated electronics, propulsion, and aerothermodynamics and configuration needed major resources; *structures and materials required more than a third of the total budget.*

This scaling of the criticality of technology into seven areas (based solely on dollars expended) reflects the relative magnitude of the problem in these areas. The issues associated with the Shuttle life-support systems and crew monitoring (addressed in the biotechnology area) were minor compared to reusable thermal protection, composite materials, thermal control and radiators, and composite payload-bay doors—all of which required significant advances in the state of the art.

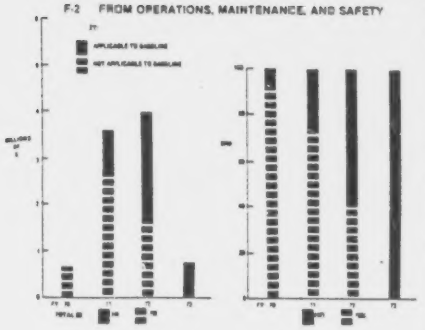
Nearly 90% of the funds were spent in the first three years of the four-year program. This timing of expenditures will be commented on later.

Conduct of the Program: Several key facets of the technology program promoted success. First was the role of government vs. the role of industry. NASA's prime role in this program was to establish requirements for each discipline. These requirements were based on the central control which the government held in understanding the configuration as it evolved in Phase A and B studies conducted concurrently with the technology program. Various governmental organizations also played a central role by providing test facilities lacking in industry. This was particularly true for wind tunnels,

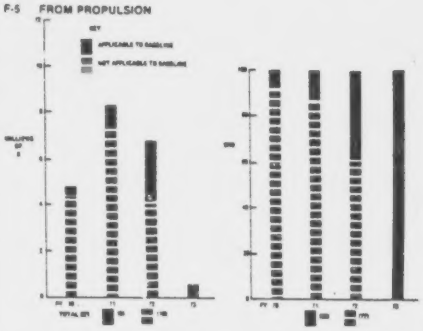
PAUL E. FITZGERALD JR., at left, serves as manager of advanced technology for the Michoud Div. of Martin Marietta Aerospace. He spent 20 years with NASA and DOD beginning in 1958 when he joined NASA-Langley as a wind tunnel test engineer. In 1962 he went to NASA-Johnson as project engineer on the first Little Joe II flight test vehicle and later on the Apollo Lunar Module ground-test vehicle certification. From 1969 to 1976 he managed the center's Advanced Development Program, which for four years focussed on Shuttle technology. He has also served in advanced R&T planning posts for the Naval Underwater System Center. **EDWARD A. GABRIS** manages the Transportation Systems Office in NASA's Office of Aeronautics and Space Technology. He has responsibility for technology for space transportation of the '90s and for chemical propulsion research and technology. Previously he managed work on technology development payloads for Shuttle and Spacelab. At NASA-Ames he managed a sound rocket program that launched almost 50 solar physics research payloads in four years.

TECHNOLOGY YIELDS

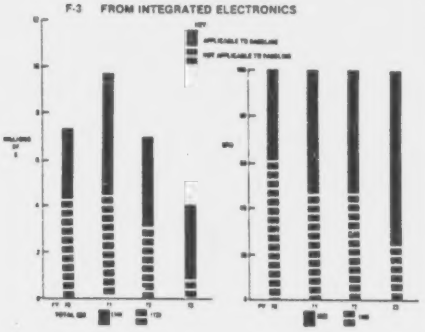
F-2 FROM OPERATIONS, MAINTENANCE, AND SAFETY



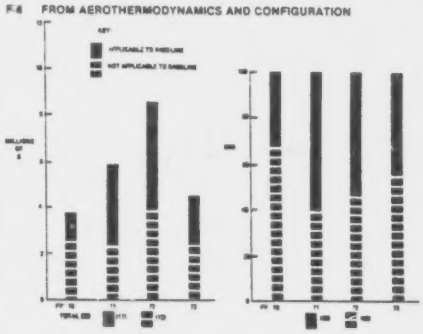
F-5 FROM PROPULSION



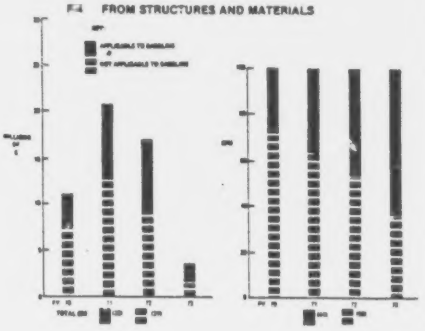
F-3 FROM INTEGRATED ELECTRONICS



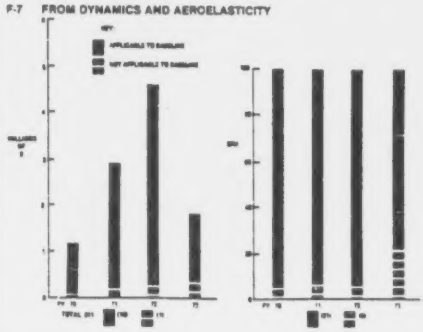
F-6 FROM AEROTHERMODYNAMICS AND CONFIGURATION



F-4 FROM STRUCTURES AND MATERIALS

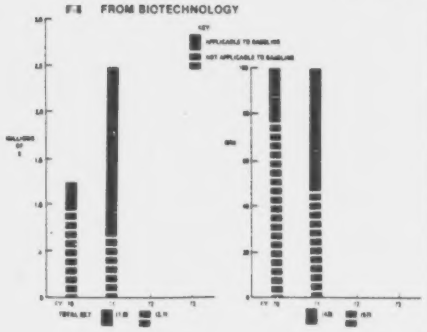


F-7 FROM DYNAMICS AND AEROELASTICITY

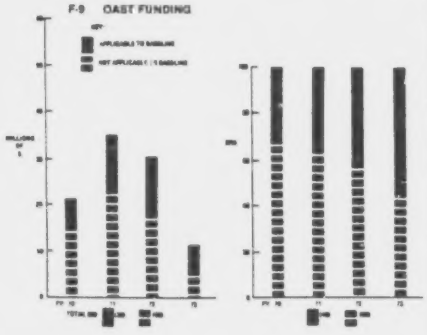


TECHNOLOGY YIELDS

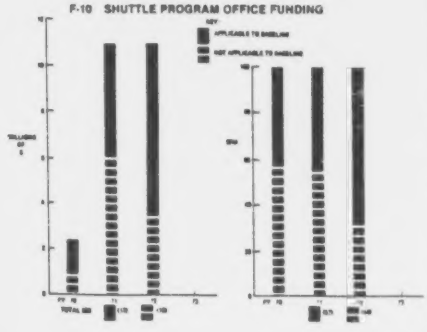
F-8 FROM BIOTECHNOLOGY



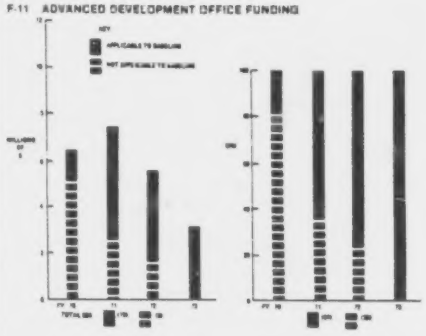
F-9 OAST FUNDING



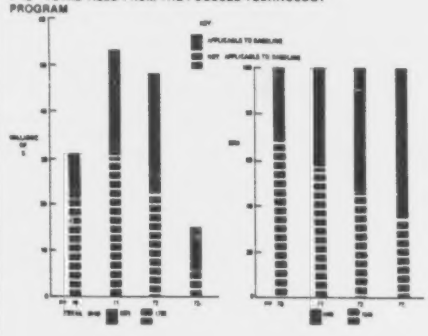
F-10 SHUTTLE PROGRAM OFFICE FUNDING



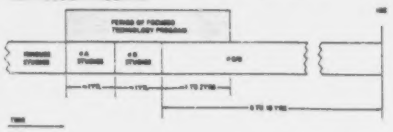
F-11 ADVANCED DEVELOPMENT OFFICE FUNDING



F-12 TOTAL YIELD FROM THE FOCUSED-TECHNOLOGY PROGRAM



F-13 IDEALIZED TIME FRAME FOR THE SPACE SHUTTLE TECHNOLOGY PROGRAM



arcjets, and propulsion test stands.

The contractor's role in the technology program was that of designer, manufacturer and tester of components, breadboards and brassboards according to government-supplied requirements. For this work approximately 80% of technology-development funds went to industry. In addition, industry liberally used its Independent Research & Development (IR&D) funds to augment the government R&T funding in those areas where industrial expertise was predominant.

This clear definition of roles for government and industry represents a primary reason for the success of the focused-technology program.

The willingness of industry to "play the technology game" was vital to the success of the program. Although industrial firms do not make substantial profits in such technology programs, they can gain leverage for winning subcontracts in a major program. Nearly all the eligible aerospace contractors were willing to bid to participate in the Space Shuttle focused-technology program. This allowed NASA to utilize the available wide resources of industrial expertise.

A third factor in success was the openness with which information was exchanged between the government and industry. The speed of this information flow was aided by the fact that none of the data was classified.

In summary, the following three factors proved the most important in executing the focused-technology program:

- Clearly defined and understood roles for government and industry.
- Willingness of industry to cooperate in the "technology game."
- Openness in the flow of information.

Technology Yield. How can the success of a large government/industry endeavor such as the Space Shuttle focused-technology program be judged? "Technology yield" offers a measure in terms of funds expended.

For the purpose of this discussion, we define "technology yield" as the percentage of program dollars spent for hardware, software, concepts, and operational procedures that found their way directly into the Shuttle baseline configuration.

The technology yield from each area may be summarized as follows:

Operations, maintenance, and safety. Although only modest sums went to this work (F-2), their effectiveness can be seen in the rapidly increasing percentage of applicable technology in 1972 and 1973. Major efforts in this discipline centered on lightning protection, definition of the launch processing system, and a reduction in the Shuttle turnaround time.

Integrated electronics. Some $26M was spent on integrated electronics (F-3). Major efforts included avionics systems architecture and development of a new software language, the Shuttle fuel cell, and numerous electronic components (including a high-density-data-storage tape recorder). The Houston Assembly Language (HAL) required more than four years to develop and cost more than $5 million. The new language is the standard today for STS and other space programs.

Structures and materials. More than a third of the total technology funding was spent in structures and materials (F-4). The particular efforts included the development of—

—Advanced carbon-carbon heat shielding for the nosecap and wing leading edges (where temperatures could reach 3000 F).

—Reusable surface insulation for the remainder of the vehicle (capable of withstanding 2200 F).

—Some advanced composite materials (primarily in the main-engine structural support, center-body struts, and payload-bay door.

—The Shuttle docking system.

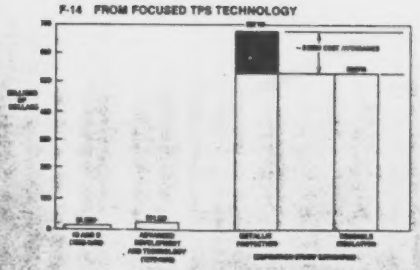
The toughest task was the development of reusable surface insulation. Three contractors focused on this technology for more than five years and spent about $11 million on characterization of silica and mullite tiles. Development of silica tiles was the breakthrough that made the Shuttle reusable. This major development, begun as an industry IR&D program, was brought to fruition by the focused-technology program.

Propulsion. F-5 shows the technology yield for propulsion. Fiscal years 1970, 1971, and most of 1972 produced a very low yield. That happened because initially oxygen/hydrogen was baselined not only for the primary propulsion system (the Shuttle main engine) but also for the orbital maneuvering engines, reaction-control system, and auxiliary power unit. System tradeoffs (conducted the first two years of the program) proved this technology would be too complex, heavy, costly and unreliable to be used on the Orbiter. The final year of the Shuttle focused-technology program focused on storables and they proved 100% applicable. Thus, although the technology effort of the first two years did not come to fruition for design, the program nevertheless eventually produced the information needed for the baseline.

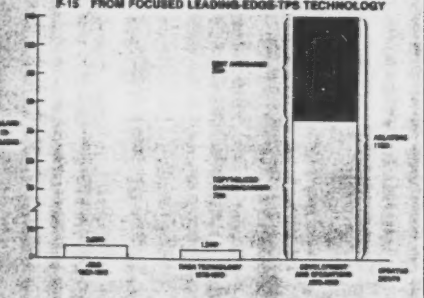
Aerothermodynamics and configuration. F-6 shows the funding distribution and percentage of applicable work developed in aerothermodynamics for the Shuttle baseline. Since the final configura-

SHUTTLE COST AVOIDANCE

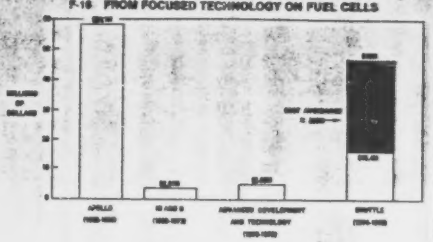
F-14 FROM FOCUSED TPS TECHNOLOGY



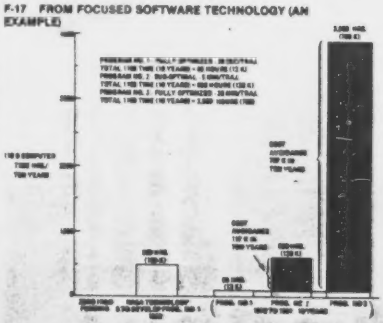
F-15 FROM FOCUSED LEADING-EDGE-TPS TECHNOLOGY



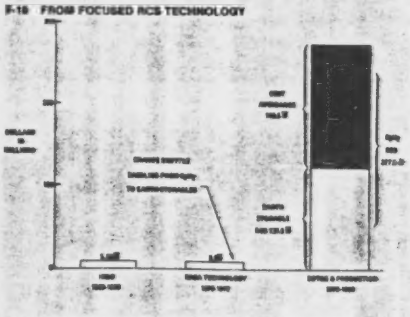
F-16 FROM FOCUSED TECHNOLOGY ON FUEL CELLS



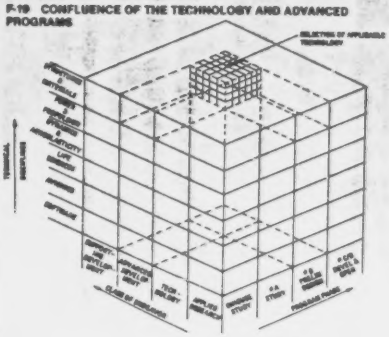
F-17 FROM FOCUSED SOFTWARE TECHNOLOGY (AN EXAMPLE)



F-18 FROM FOCUSED RCS TECHNOLOGY



F-19 CONFLUENCE OF THE TECHNOLOGY AND ADVANCED PROGRAMS



tion was not selected until 1972, much of the "nonapplicable" work concerned configurations other than the one finally selected. Most of the funds for this category supported building and testing wind-tunnel models at various NASA and contractor facilities. This category also included important mathematical modeling and analytical-tool development aimed at reducing the number of wind-tunnel hours needed. Wind-tunnel testing spent on Shuttle aerodynamics totaled nearly 80,000 hr. Future programs will require significantly fewer hours due to the development of mathematical models and high-powered computers to solve complicated models within a reasonable time.

Dynamics and aeroelasticity. The technology program spurred much productive work in dynamics and aeroelasticity, both analytical and test-related. The NASTRAN program (developed for Apollo) was extended to several new areas and served well in analyzing structural dynamics of various Shuttle configurations. Most of this work was considered applicable to the Shuttle baseline (F-7).

Biotechnology. As can be seen from F-8, it was decided after two years that biotechnology issues (including life-support systems and food services) were well in hand for the Shuttle program and that no further technology funding would be required.

F-9, F-10, and F-11 depict the yield from the three fund sources: OAST, Shuttle Program Office, and OMSF Advanced Development. The results are obvious: funds for tasks toward the research end of the spectrum (generally OAST funds) were less effective than funds from the other two resources.

F-12 shows the total breakdown for FY70-73. It illustrates that more of the work became applicable as nonqualifying tasks dropped off toward the completion of the program.

Lessons Learned: Although often is may not be prudent to generalize results of a given effort, because of the pitfall of oversimplification, we believe it desirable to list lessons learned on this program to guide future, similar efforts.

The first three "lessons learned" we described under program conduct: clearly defined roles for government and industry; willingness of industry to participate in the technology program; and free and rapid flow of information among government organizations and industrial groups. To these we add the following inputs:

• Proper criteria needed for starting and stopping work. When designing a focused-technology program in support of a major flight program, there is a tendency to start too early and end too late. A degree of program definition must exist to focus technology projects. NASA's use of the phased development/procurement process for its major programs allows dovetailing technology projects having a degree of program definition.

The normal sequence of this process starts with a NASA in-house study designed to determine feasibility of a concept. This in-house study yields an initial conceptual design and an estimation of the types of system required in the first approximation of system sizing. It also provides the primary estimate of critical technology required. At this point the need for a focused-technology program can be addressed, but a program should not necessarily be started because technology issues will not necessarily be well defined.

Following the in-house study, contracted efforts are considered (such as Phase A studies) aimed at confirming in-house judged feasibility of the prospective space system. It is in this period that a focused technology program can be initiated since by their technology options and issues should be fairly well identified. It allows three to four years of technology effort before final technology selection (which generally occurs in the first two years of Phase C/D of the program). The cutoff point on technology must occur at this point because the prime contractor will have baselined it, in selection of subsystem contractors. F-13 shows an idealized focused-technology time-phasing chart.

• Proper split of effort between government R&T centers and government programs centers. The best expertise available should be used to address each technology issue without regard to the R&T or program interest of the government organization. There never was a clear dividing line in the Space Shuttle focused-technology program between the class of effort undertaken by NASA R&T centers and NASA program centers. Both were involved in some subsystem-level development as well as in basic technology work.

• Government in-house technology-transfer mechanisms. The question of technology transfer from personnel working on the technology program to personnel working on the major flight program is always a major concern. It is important to recognize that new technology will be used by personnel managing a major flight program only if they are thoroughly familiar with (and have firsthand knowledge of) the advantages and disadvantages of the new technology. *It is not sufficient to demonstrate the maturity of the new technology; it is equally important that the user be an active participant in the demonstration.*

The history of innovation is full of examples of the gap in time between demonstration of the maturity of a new technology and its first full-scale

(Continued on page 72)

Shuttle Focused Technology
(Continued from page 67)

application. This usually happens because the user community had not developed the technology and did not have confidence in it. This situation argues strongly for a "handover" of basic work (accomplished in an R&T center) to a program center where the effort continues into advanced development and demonstration. Other mechanisms of a technology transfer, such as symposia and good documentation of technology results, do not appear to have as significant an impact.

- Focused technology can have much higher yield than unfocused. In the mid-Sixties, the R&T manager of a major aerospace research laboratory ran a survey of some 500 tasks conducted in his laboratory over the previous ten years. He discovered that only three had progressed to the marketplace and only one of those three proved profitable—resulting in a yield of less than 2/10 of 1%. Too often companies and governments become involved in research for the sake of research alone. This tendency is eliminated by a focused-technology program which has an immediate end use if the technology is successful. Informal assessments of company IR&D programs indicate that this class of R&D generally yields less than 10%. In contrast, the Space Shuttle focused-technology program, spending $146 million over a four-year period, resulted in a yield of approximately 46%!

- Properly run focused-technology programs can save the real program substantial funds. During the Space Shuttle focused-technology program, numerous tradeoff studies guided the decision-making process and the choice of a given technology baseline. A number of these tradeoffs gave impetus to investment in one technology over another from a cost-savings point of view. F-14 through F-18 show some of the cost-avoidance values (in then-year dollars) which led to pursuing one type of technology over another (e.g. TPS, leading-edge TPS, fuel-cell, software, and RCS technology). As the figures indicate, many of the technologies funded by the government's focused-technology program had been preceded by industrial IR&D efforts.

Concluding Remarks: In the final analysis, the focusing of technology efforts on a given future program permits optimum confluence of program phase, R&T class of endeavor, and technical discipline (see F-19).

The government/industry team, which did such an outstanding job in demonstrating baseline technologies for the Space Shuttle, now stands on the threshold of adapting these, and many other, more-subtle "lessons learned," as it enters the era of the building of a space station and an American permanent presence in space.

Space Operations Center

Next Goal for Manned Space Flight?

By CLARKE COVINGTON and ROBERT O. PILAND
NASA Johnson Space Center

The various and flexible systems of this concept not only meet requirements of a wide range of roles and missions, but also permit imaginative organizational arrangements for evolutionary development

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The Space Shuttle approaches its initial orbital flight test. Success will release a long-pent set of expectations for the U.S. manned space flight program. Future space activities will surely require expanded manned operations in space, and significant advances in space operations inherently require long gestation and development periods. Furthermore, developments in both technology and operational capability need a long-term goal to focus their activities to be most effective. Although it sometimes is not stated openly, there frankly is a need for a central, hard goal to maintain the dedication of participants in the space program and the interest and enthusiasm of young people in space technology to motivate their pursuing engineering and science careers.

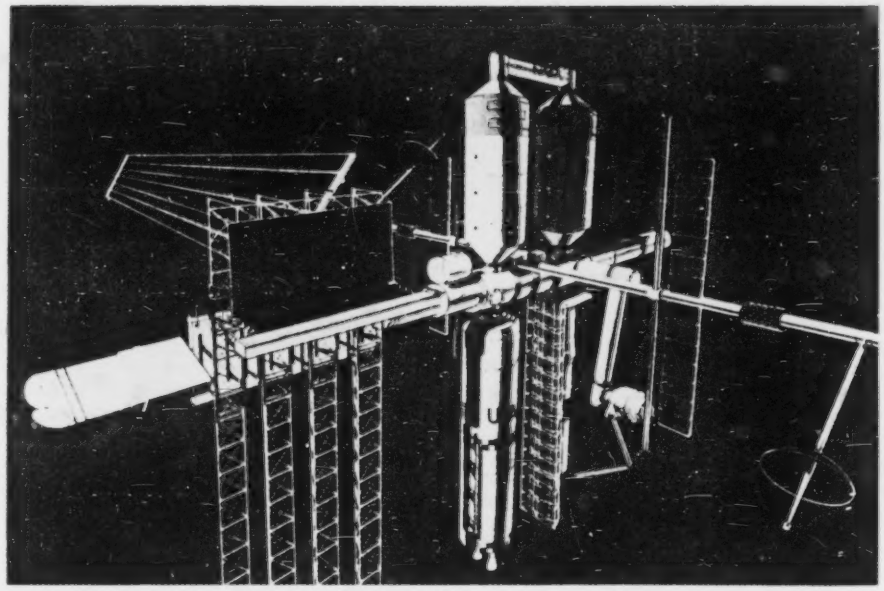
Although hundreds of proposals have been made for the next major space goal, including power satellites and space colonies, the strongest candidates for manned space flight can be grouped into the following five areas:

- Extensive Shuttle use.
- Permanent manned facility in low Earth orbit (LEO).
- Manned geosynchronous sortie mission.
- Permanent manned facility in geosynchronous orbit (GEO).
- Manned lunar sortie mission with or without a lunar base.

The first of these, exercise of Shuttle capabilities alone, is not an insignificant goal. The Shuttle should and will, hopefully, be exploited to the maximum. But Shuttle use, an evolutionary use, will neither require a new R&D thrust nor provide the clear focus needed for development of future technology and operations. A goal limited to Shuttle use only would represent a relatively slow pace of advancement.

On the other hand, a permanent manned GEO facility or a lunar base would bypass desirable, and perhaps necessary, evolutionary steps in technology and operational development, and both would require support that would probably exceed the scope of likely near-term funding.

The other two options, a manned LEO facility and a manned GEO sortie mission, both appear to have considerable value and represent reasonable technical and funding challenges. The operational deployment of a manned LEO facility would consolidate operations in near space, from the standpoint of both transportation and per-



The Space Operations Center (SOC) concept embraces operations as diverse as manufacturing large structures, tending free-fliers, and preparing and launching large spacecraft with propulsion units. At left here, beam-builder in action; at right, manipulator placing a spacecraft stage on strongback. Below center, two-stage manned orbital transfer vehicle (MOTV) at berth.

manency. Development of the means for manned GEO sortie missions would extend manned transportation from LEO, as provided by the Shuttle, to geosynchronous orbit. This capability would be an initial "LEO-GEO Shuttle."

In this article we describe recent thinking about a new concept for a Shuttle-serviced permanent manned LEO space station, a Space Operations Center. That name has been chosen to convey its mission-oriented role of construction, assembly, and servicing of space systems and spacecraft, and not just its being a site for conducting experiments and gathering scientific and applications data. We briefly review previous space-station concepts, compare future space goals, discuss objectives for a Space Operations Center, and describe the results of its initial analysis. NASA has no plans yet, we note, to implement such a concept. Currently planned studies simply explore the concept.

Space-Station Concepts: NASA has performed and sponsored studies of space stations off and on for many years. F-1 shows a 1967 concept that illustrates the thinking of the day. At that time many people thought artificial gravity would be required for long-term living in space, and the concept shown has a crew living area that rotates around a zero-*G* hub that houses inertially oriented experiments. The picture also shows the dependence of the station's configuration on its launch vehicle, Saturn V, as evidenced by its diameter and the use of a spent stage for a counterweight.

Apollo and then Skylab missions showed that a null-gravity environment contributes to fluid shifts, some cardiovascular deconditioning, loss of some bone calcium and muscle mass, and modest changes in the blood, but all these changes appear reversible. Such changes do not preclude longer exposure times than the 83-day Skylab mission, and no physiological changes uncovered suggest that a high level of human performance should not be expected in space.

Consequently, space-station studies shifted to zero-*G* concepts. Serious studies of a new logistics vehicle, which became the Shuttle, were under way, and space-station concepts soon evolved to the configuration shown in the 1970 illustration in F-2. It employs modules fitted inside the payload bay of the Shuttle concept of the day then assembled by manipulator into a space station.

(Meanwhile, the USSR was moving pragmatically ahead with their approach (F-3). Beginning in 1971 the Soviet Union launched the first of six 20-ton

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Salyut space stations. In 1979 Salyut-6 carried a two-man crew continuously for 175 days. The Salyut was visited periodically by manned Soyuz spacecraft and unmanned Progress vehicles each carrying 5000 lb of supplies. Both spacecraft can execute automatic, unmanned docking and can resupply propellants across the docking interface. A Soyuz always remains docked to the station for emergency return to Earth. The crew performed several operations, such as modular equipment replacement for station maintenance and attachment of a 10-m radiotelescope to the station's exterior. The station carried multispectral Earth-resource survey cameras, materials-processing furnaces, a liquid-helium-cooled infrared telescope, a gamma-ray telescope, a long-duration exposure platform, and medical equipment.)

Such NASA space-station studies had been largely applications- and experiment-oriented in their requirements. Consequently, the large "shopping lists" of possible experiments had a major influence on design requirements. Many of these ended up in conflict. Some experiments required one orientation, while others wanted another. Some required very low gravity, while others need some artificial gravity. There were also conflicts in altitude and inclination and other operational parameters. The resulting design concepts were complicated, and data handling and transmission requirements associated with the experiments were extremely high, as were estimated system costs.

But as the Shuttle moved along through development, concepts for long-duration experiments and applications began changing from "onboard," to "free-flying" with periodic servicing. In addition, ideas for advanced space systems predicted a need for large systems—of a size requiring construction in some fashion in space. It was this shift in thinking that paved the way for the Space Operations Center (SOC) concept.

Objectives of Permanent Manned LEO Facility: Assume with us that the next ten to twenty years will bring requirements for large, complex space systems and that geosynchronous orbit clearly becomes a primary operational arena. SOC then can be foreseen to have these chief objectives, which following paragraphs amplify—

—Construction, checkout, and transfer to operational orbit of large, complex space systems.

—On-orbit assembly, launch, recovery, and servicing of manned and unmanned spacecraft.

—Tending of co-orbiting free-flying satellites.

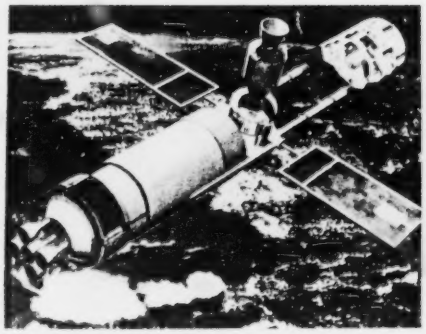
—Development of the capability for permanent manned operations in space with reduced dependence on Earth for control and resupply.

This list noticeably does not include on-board science and applications. Tended free-flying satellites would cover most such work. In fact, experiment and applications requirements will not be design drivers. SOC will be "optimized" to support *operations*. Experiments or applications that can tolerate SOC's operational parameters can be operated on board it, and, of course, an entire dedicated module can be attached to it at a berthing port.

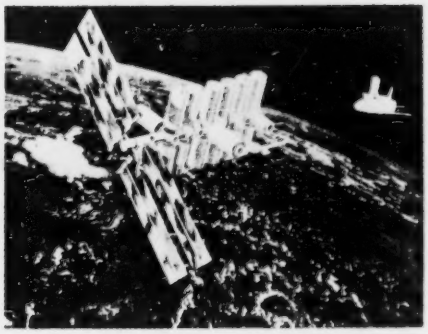
Space Construction: In the Eighties the Shuttle will be used in developing space construction methods and in constructing certain operational systems. However, current studies indicate that in several respects the Shuttle will not be able to handle directly the construction of some of the large and complex space systems under consideration. As shown in F-4, future systems could include large power modules with solar arrays in the 200-500 kw range, communications platforms with areas as large as 4000 m^2, and high-resolution parabolic antennas with diameter of 100 m or more. A permanent facility in space better suits conducting construction operations for such large structures and systems. SOC would support the flight development of the construction equipment and operational techniques begun with the Shuttle, and would then serve to construct, check out, and transfer to operational orbit such large systems.

On-Orbit Assembly, Launch, Recovery, and Servicing: Such work will require ability to fly manned and unmanned missions to GEO. A reusable manned orbit transfer vehicle (MOTV) will ultimately be required to perform the required

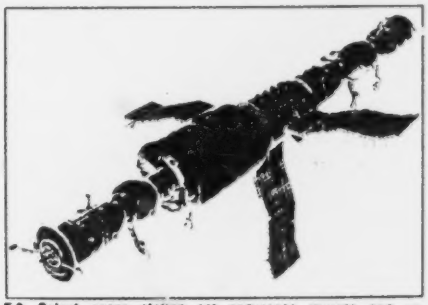
CLARKE COVINGTON, left, heads the System Design office responsible for conceptual design and system analysis of advanced space systems at JSC. He joined NASA in 1962. In the early '70s he was project engineer for the U.S.-USSR mission feasibility study and manager of design for the NASA Apollo-Soyuz docking module. For the past four years he has managed system definition within the JSC solar power satellite (SPS) concept-evaluation program. Covington holds an MSME from the Univ. of Texas. **ROBERT O. PILAND,** associate director for program development in JSC's Engineering and Development Directorate, has been involved in aeronautical and space R&D since joining NACA in 1947. For the past five years he has managed JSC's advanced programs, including its studies of the SPS and Space Operations Center. Before this assignment he served as director of JSC's Earth Resource Laboratory, manager of its Experiments Program Office, and deputy manager of the Apollo Spacecraft Program. A graduate of William and Mary, he also received a Master's degree in environmental management from the Univ. of Houston.



F-1 Concept for space station from 1967 reflecting the thinking of the day. Artificial gravity shapes design.



F-2 Configuration from 1970 featured Shuttle-delivered modules and assumed zero-*g* operations.

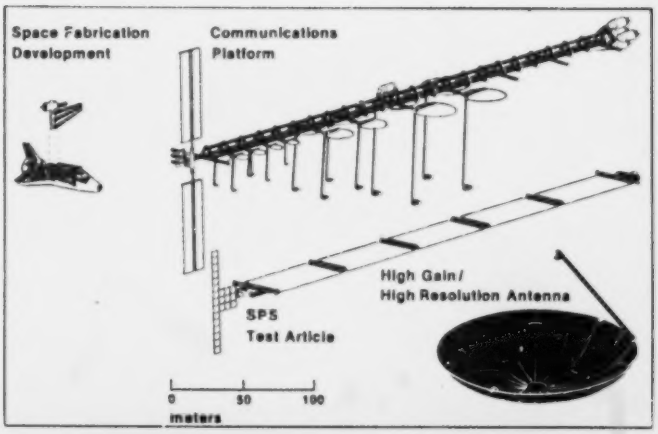


F-3 Salyut space station set endurance records and underscored combined orbital operations.

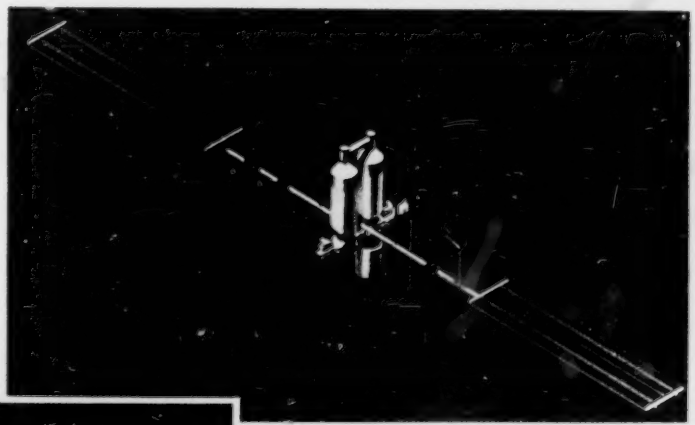
services. A single Shuttle mission can deliver a 5000-lb payload to GEO using an inertial upper stage. The assembly of two or more stages together in orbit to form a multistage vehicle too heavy for a single Shuttle launch opens up the possibility of large payloads to GEO and higher-energy, deep-space missions. Studies have shown the feasibility of assembling separately launched stages using the Orbiter as an assembly base, but the operational aspects appear formidable. By comparison, the on-orbit basing of a staged assembly allows not only operational advantages, but also offers the economy of recovery and space servicing of reusable stages for both unmanned vehicles and MOTVs. In addition, a permanent facility in orbit, with proper orbital phasing, can recover a payload returned from a planet and quarantine it before risking delivery to Earth.

Tending Free-Flying Satellites: For best results some space operations, such as construction, will require crew participation almost continuously. Others, such as routine data collection, can be done satisfactorily without crew intervention. And some operations actually proceed best without the disturbance of human presence, although perhaps requiring periodic servicing, adjustment, fault detection, and repair managed better by a human than a robot. Such operations include materials processing, which requires extended periods of extremely low acceleration, and a large space telescope, which can be contaminated by nearby crews, but may need frequent film and instrument replacement, calibration, etc. The SOC concept operates satellites of this kind in a co-orbiting mode at whatever separation distance may be required, with recall command, rendezvous, and berthing to the Center for servicing when necessary. Tending co-orbiting satellites is similar in equipment and operations to supporting an orbit-transfer vehicle (including means to berth payloads the size of the Orbiter bay, access to the interior and exterior of the serviced vehicle, rendezvous and berthing remotely controlled from the SOC, and servicing and repair facilities.)

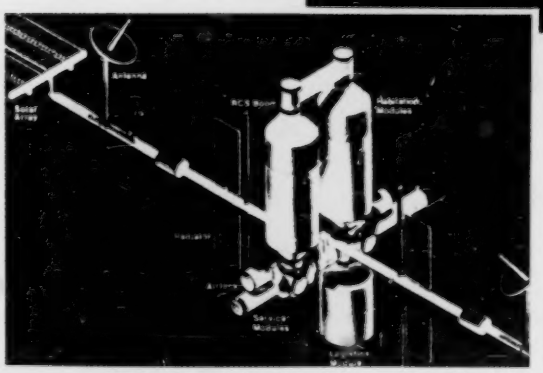
Space Operations with Reduced Dependence on Earth: SOC should move toward permanent manned operations in space without frequent resort to Earth for resupply and day-to-day control of operations. Reducing dependence on supplies from Earth significantly alters design requirements for electrical power generation and storage, recycling atmosphere and water, on-board health maintenance (which provides inherent clinical physiological data accumulation), and comprehensive emergency considerations (which in turn involves a high degree of redundancy both in systems and living quarters). The present mission management and control process is characterized by people-intensive ground monitoring and control involving large supporting facilities and highly integrated ground- and flight-crew operations. To reduce dependence on



F-4 The typical space construction projects under study, treating very large structures, some with large power modules, lend themselves to SOC operations.



F-5 Rudimentary Space Operations Center would be able to sustain crew and operations for ninety days without assistance—without presence of a Shuttle.



F-6 Pair of identical service modules form the central spine of SOC. They offer several docking and berthing ports for the Orbiter and modules.

Earth monitoring and control, SOC would have to provide for increased systems monitoring, fault isolation and failure analysis, and storage and callup of extensive sets of data for on-board control of the stations and missions.

SOC "Core" Elements: The Space Operations Center would be a self-contained facility built up of several Shuttle-launched modules. With resupply, on-orbit refurbishment, and orbit maintenance, it would operate continuously for an indefinite period. It would usually be manned, but it could be operated automatically.

Safety of both the SOC and its crew would be a major design consideration. Through subsystem and module redundancy SOC could sustain itself and its crew for ninety days without assistance in

the event of a major failure, including the functional loss of an entire module.

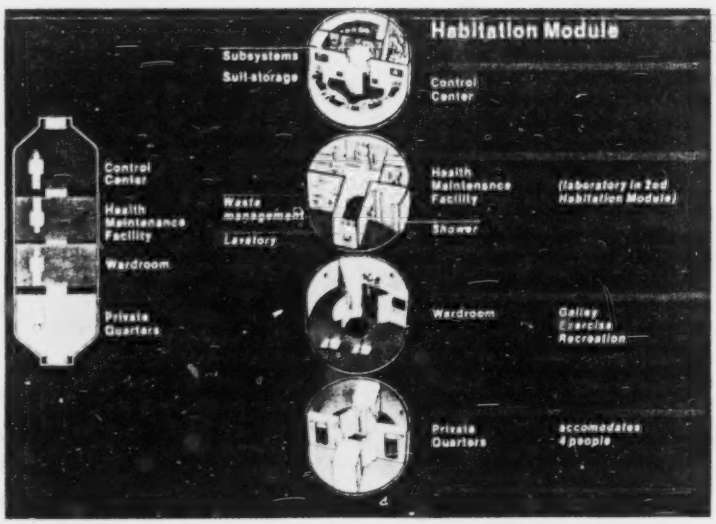
F-5 shows the arrangement of SOC core elements. Two identical service module halves form a central spine having several docking/berthing ports for other modules and the Orbiter. Each service module provides electrical power, generated by two large solar arrays on long booms; guidance, control and stabilization; reaction control; communications; and airlocks for EVA. These independent but interconnected sections give the necessary redundancy of critical systems.

Two habitation modules are berthed to the service module. Each contains a command center capable of controlling the entire SOC, private quarters for a crew of four, food-preparation, hygiene, and waste-management facilities, and exercise and recreation equipment. In addition, one module has a health-maintenance facility, and the in it will help develop a better understanding of the physiology of living and working in space.

The two habitation modules are joined at the "top" by a tunnel. This gives each two exits in an emergency. The tunnel also contains Shuttle docking ports alternative to the primary docking position at the end of the service module.

A logistics module, normally berthed to the service module, stores consumables and spare parts. The Shuttle would replace it during resupply visits, thus avoiding large-scale transfer of cargo. The service and habitation modules would always carry emergency stores to hedge against loss of access to the logistics module.

Our initial studies have in good measure assumed available subsystem technology. SOC subsystems draw heavily on Skylab, Shuttle, and Power Extension Package hardware. New subsystems can be added or tested as they become available.



F-6 Typical layout of a habitation module. Much study remains to be done before choosing a firm design.

other module a small laboratory. The arrangement of space within the habitation modules will be governed by various factors that have not yet been adequately defined. F-6 illustrates a plausible layout, but not necessarily the best one.

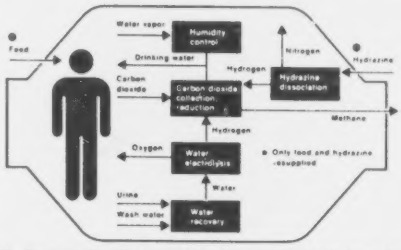
The health-maintenance facility is more than a conventional clinic. It primarily serves to treat minor illnesses and injuries—including making X-rays and conducting minor surgical procedures—but, in addition, it provides extensive monitoring of crew health and body functions. Data obtained

An exception to this approach was the environmental control and life support system (ECLSS). In most previous programs (except Skylab) fuel cells have provided both electrical power and water. Since the SOC uses solar cells for power, water must be either resupplied or reclaimed. Reclamation of both water and oxygen was selected to avoid very large resupply requirements. F-7 shows a simplified schematic of the system chosen. The only resupplied consumables are food and hydrazine, the latter being dissociated to make up both atmo-

spheric nitrogen leakage and the hydrogen requirement of the Sabatier reactor that reduces the carbon dioxide exhaled by the crew. Hydrazine is also used as a monopropellant in the reaction-control system to simplify resupply requirements.

The regenerative ECLSS has been the subject of an extensive development effort for several years, including over 1700 hr of tests on a first-generation system and several second-generation subsystems. The remaining second-generation hardware should be delivered and prototype testing of an integrated system should be completed before the end of this year. Plans include modifying the system as necessary and making manned system tests in a 20-ft vacuum chamber.

The communications and tracking system also represent a significant performance increase over previous space systems, primarily in the number and diversity of communications links (F-8). Hardware requirements can be satisfied by Orbiter-type equipment in most cases.



F-7 **Regenerative life-support system** has this basic form. The only resupplied consumables are food and hydrazine.

SOC Operations Elements: Besides service, habitation and logistics modules, the SOC concept embraces construction and flight-support facilities (F-9). A control cab and Shuttle-type manipulator on a movable boom serve both.

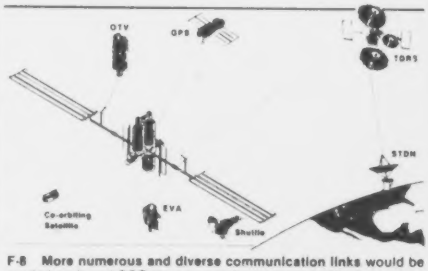
The construction facility would fabricate and assemble large structures; install, integrate and check out subsystems, and separate and launch a completed system to its operational orbit.

The principal elements of the facility are construction equipment and a holding fixture. The beam builder is one type of construction equipment. From flat stock it makes triangular-truss beams in any desired length. The fixture holds the beams correctly and positions the beam builder to produce additional beams in the locations desired. The holding fixture also moves the structure lengthwise to allow attachment of secondary structure and subsystems at a fixed worksite. Since its design depends on the article being constructed, the fixture must be replaced or reconfigured for each different structure.

A manipulator and tools associated with the holding fixture aid the installation of subsystems. The opening illustration shows a solar-cell blanket being dispensed from a container attached to the holding fixture. EVA will often be required to provide the needed dexterity; most operations will not repeated enough for automation.

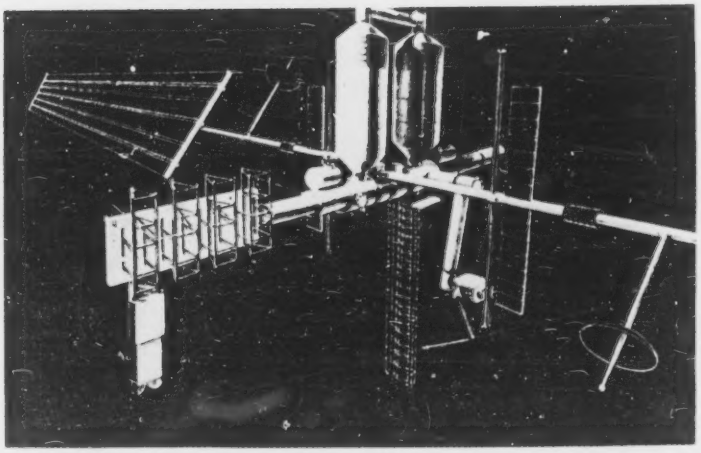
The flight support facility serves to assemble, check out, and launch multistage solid-rocket vehicles; assemble, check out, fuel, launch, and recover the MOTV, and recover and service co-orbiters.

A strongback berthed to one of the service-module ports (opening illustration) forms the main member of the assembly unit for solid-rocket stages. As stages and payloads are delivered by the Shuttle, they are placed on the strongback by the SOC manipulator. When all stages have been delivered, mechanisms on the strongback mate the stages and payload to complete the assembly. The vehicle is then checked out. For launch, a tilt table rotates the vehicle away from the strongback and separates it from the SOC. The vehicle then moves to a safe distance before final orientation and ignition.



F-8 **More numerous and diverse communication links** would be carried on board SOC than on previous space systems.

The MOTV, a two-stage reusable manned vehicle for GEO sortie missions, parks at a lower docking port of one of the service modules (opening illustration). Before launch, it is fueled from the Shuttle (or from storage tanks on the SOC), using propellant-transfer equipment on the SOC. For launch, the MOTV separates from the docking port and moves to a safe distance from the SOC before engine ignition. The first stage returns to the SOC before the second stage and is stored temporarily on the stage-assembly strongback. After completion of a mission, the second stage with crew module returns to the SOC and either docks or is berthed by the manipulator to its port on the service module. The first



F-9 SOC features construction and flight-support facilities, in the general scheme illustrated here. Note beam builder at left and manipulator on strongback at right. The opening illustration of the article shows more details, notably of rocket-stage assembly.

stage is mated to the second using the manipulator, and the vehicle is then checked out in preparation for the next mission.

The same units service co-orbiting satellites. Either the MOTV or the Shuttle docking port can dock a satellite to allow pressurized access to its interior.

Concluding Remarks: SOC requires additional exploration both in terms of its operational values and its design. In particular, its justification depends on the actual "demand" for large space systems. And even if requirements for large systems materialize, they must be shown to exceed the capability of the Shuttle, thereby necessitating a SOC-like facility.

The SOC concept covers assembly, launch, and recovery of space vehicles. Mission analyses are required to determine under what conditions such assembly in space will be effective and for what types of systems.

SOC would service co-orbiting automated satellites. Many satellites requiring servicing will not be in the orbit of the SOC, and it is likely that they will be most effectively serviced by the Shuttle. But certain types of satellites, not sensitive to orbital requirements, should benefit from frequent servicing and manned interaction with a SOC-like facility.

The system technology that should be incorporated in the SOC represents a considerable challenge of *decision*. In the past, performance based on weight requirements required the selection of the most advanced technologies available. The SOC presents a somewhat mixed situation. In certain areas, existing technology is adequate. On the other hand, it may be necessary to develop new criteria for deciding between an existing and a more advanced technology. The demonstration and use of advanced technology may be a reasonable objective itself.

Without question SOC will necessitate advancing the state of the art in many areas. Variable-geometry structure and controls interaction, software planning and management, construction and vehicle assembly, and servicing represent challenges.

Integrating systems to gain performance advantages requires careful consideration in the SOC concept. There are obvious opportunities to integrate, in various ways, the life-support system, fuel cells, electrolysis units, and propulsion system, making them interdependent. The analyst would certainly be able to show performance gains from such interrelationships. The system developer and the operators, however, might prefer to maximize the independence or modularity of these systems.

The SOC offers important options from the standpoint of program development. Its necessary elements lend themselves to a variety of organizational arrangements for development, including multi-center, multi-company, and multi-national participation. Obviously these options need to be considered from many standpoints.

The SOC concept also lends itself to evolutionary development. It would be very desirable if the various elements of the SOC could be developed somewhat independently and tested with the Shuttle, serving useful purposes as independent operational elements before being integrated into the whole SOC system. An obvious example: a power module designed for use as the service module of the SOC as well as for automated platforms. In short, the concept offers room for imagination and ingenuity in planning an evolutionary development.

We believe the aerospace community should now begin to weigh the next goal for manned space flight. The SOC preliminary study we hope will stimulate and encourage discussion—help guide both further studies and technological developments. ■

AN AIAA LIQUID PROPULSION TECHNICAL COMMITTEE ASSESSMENT

Liquid-Rocket Propulsion Technology

Edited by Robert L. Sackheim, Committee Chairman.
Contributors: Daniel L. Balzer, RCA Astro-Electronics; Larry B. Bassham, Aerojet Liquid Rocket Co.; Donald L. Bond, Ford Aerospace and Communications Corp.; Richard D. Cannova, Jet Propulsion Laboratory, CalTech; Ralph N. Eberhardt, Martin Marietta Aerospace-Denver; Daniel A. Heald, General Dynamics/Convair; Lee W. Jones, NASA Marshall Space Flight Center; Howard Macklis, TRW Space and Technology Group; James A. Martin, NASA Langley Research Center; George F. Orton, McDonnell Douglas Astronautics Co.-St. Louis; Robert L. Sackheim, TRW Defense and Space Systems Group; Donald J. Simkin, Rockwell International; Horst Wichmann, The Marquardt Co.

The federal government should reinstate and firmly commit a long-range integrated program to develop liquid-rocket technology for the coming generation of space systems

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Space systems have become a major factor in our daily lives. We depend upon our national space assets for communications, weather forecasts, military defense, terrestrial resource management, navigation, and the generation of new and vital scientific data for all mankind, to name only the most notable. All depend directly on space transportation and therefore on the high-performance rockets that power our vehicles. Transportation propulsion systems define the limits of size, mass, cost-effectiveness, and availability of all space systems. The propulsion system represents upwards of 85% of the mass of any space system going into orbit. As we look to future systems, we find that our vehicles must have better propulsion, particularly better liquid rockets, to power them. This assessment explains why. It defines our many liquid-rocket needs. They need and deserve support—funds, manpower, and development planning.

A marked slowdown in rocket technology occurred after the successful Apollo manned lunar landing in 1969. Although the pace quickened somewhat with the advent of the Space Shuttle program in 1972, it never recovered the original zest of the late 1950s and 1960s. The Space Shuttle's systems represent a state-of-the-art landmark.

Today, most problems of the older liquid-rocket propulsion systems are under reasonable control, as attested to by the very low failure rates of the past decade compared with the 40% failure rate of the '50s and the 10-20% failure rates of the '60s. Propellant combinations, moreover, appear to have become standardized (e.g., liquid oxygen (LOX)/hydrocarbon; LOX/hydrogen; nitrogen tetroxide (NTO)/hydrazine compounds). Higher-energy propellants, such as fluorine, may enter the picture, but as yet missions do not justify their use.

From 1962 to 1982 upper-stage engines were developed with little, if any, difference in technology from generation to generation, largely the combined effect of very limited funding for liquid-rocket technology after the mid-Sixties and lack of clearly defined space goals. For example, Apollo, Transtage, Lunar Module, Shuttle OMS, and MX engines have strong similarities in concept and technology. The strong technical advancement represented by the Space Shuttle Main Engine (SSME)—with its high chamber pressure, staged combustion, and high-power density pumps—has become a rarity, if not a singularity, in liquid-rocket technology.

Needs and Benefits: We must have advances in four basic types of liquid-rocket technology to improve our ability to operate in space:

- In launch-vehicle technology, to enable a ma-

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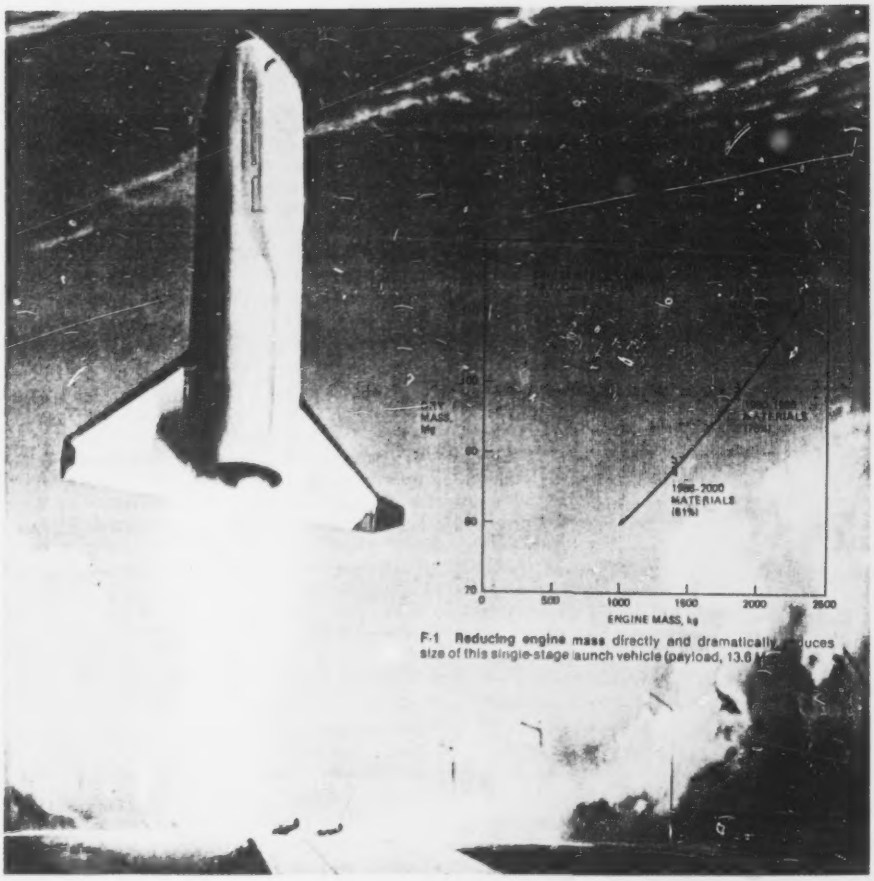


F-1 Reducing engine mass directly and dramatically reduces size of this single-stage launch vehicle (payload, 13.6 M[illegible]

jor expansion in space utilization and dramatically reduce the overall cost of space operations. A growth version of the Shuttle could increase payload delivery to low Earth orbit (LEO) from 65,000 to over 100,000 lb.

- In high-performance systems for orbital transfer, to gain mission flexibility and minimize costs in terms of spacecraft size.
- In high-performance space-storable propulsion, to upgrade planetary spacecraft and make possible efficient maneuverable spacecraft.
- In high-performance auxiliary propulsion, to increase payloads and extend orbit stationkeeping and attitude control.

All these advances must be accompanied by new or improved systems for long-term fluid storage and resupply in space. Taken together, these developments would enable important new missions to be performed and would lower cost and improve effectiveness of all U.S. space activities.

Moreover, military space missions impose different propulsion requirements in each of the above key technology areas. Military launch-vehicle technology will tend to be driven by fast response, quick turnaround, survivability, launch environment (both peace and war), and military threat.

Similarly, military OTV (orbital transfer vehicle) and on-orbit propulsion will be driven by different requirements—acceleration control, long storability and long dormancy, low observables, survivability, active defense, and minimum contamination.

As yet the U.S. has no means for high-performance, quick-turnaround launches. Projected requirements for total impulse, low contamination, and survivability cannot be met by the state of the art in OTV and satellite propulsion technology.

Much emphasis has been placed on lowering the cost per pound of payload into orbit from the current $25,000 per pound into GEO and the anticipated $16,000 per pound for the Shuttle/inertial upper stage (IUS) to about $6,000 per pound for advanced Shuttle upper stages. The following sections

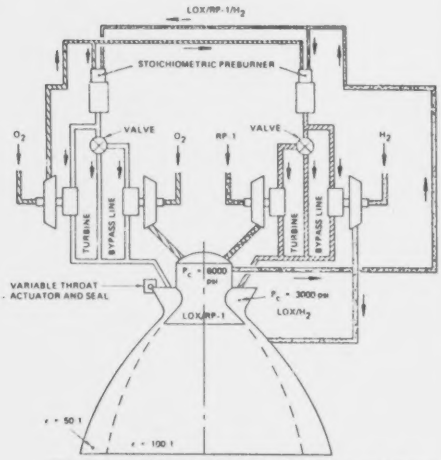
address the systems and technology needed to attain these objectives.

Transportation to LEO: Improvements will be required in the liquid-rocket engines used for LEO transportation. These improvements concern both the SSME and future engines utilizing LOX with either H_2 or hydrocarbon (HC) or both as the fuel. Salient points concern engine operating costs, engine mass, and altitude compensation.

Operating costs will drive design for all reusable hardware having higher launch frequencies than the Space Shuttle. One study indicates that $1.7 billion could be saved over the life of advanced vehicles by developing an extended-life SSME for an R&D cost of $247 million. Another study has shown that maintenance costs of liquid-rocket engines can be reduced by developing monitors to detect rate of component wear or impending failure. They would also support crew safety during flight.

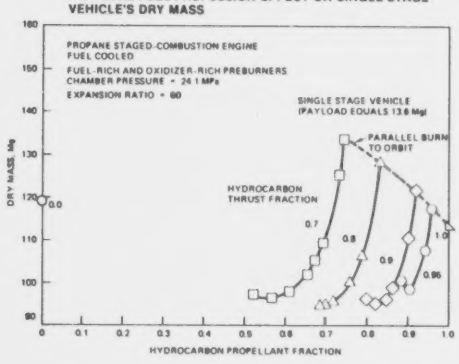
The mass of liquid-rocket engines greatly influences design options for advanced launch vehicles. An engine mass reduction of 50% in the single-stage concept shown in F-1 can bring the vehicle dry mass down more than 25%. Engine mass reduction also shifts forward the vehicle's center of gravity (CG). That lessens loads on aerodynamic surfaces and control systems, producing a further reduction in vehicle dry mass (making, for instance, the curve shown in F-1 conservative). Research in progress is directed at reducing the mass of vehicle structure, but little has been done recently to reduce the mass of liquid-rocket engines. In the near term, substituting advanced composites for more conventional materials might reduce engine mass 24%. By century's end, advanced engine designs could reduce mass over 35%. This R&D effort should be vigorously pursued.

By their nature, Earth-to-orbit vehicles fly throughout the entire range of atmospheric pressures from sea level to vacuum. Engine (nozzle) characteristics that work well at low altitudes suffer in vacuum and vice versa. The rocket-engine designer deals with atmospheric variability with several techniques, a notable one being to maximize the combustion-chamber pressure. The SSME has a higher chamber pressure than previous engines, and future engines may operate at even greater pres-

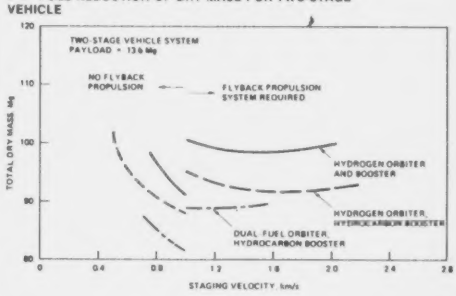


F-2 Dual-expander engine using LOX/RP-1/LH_2 offers high performance but remains largely undeveloped and unexploited.

F-3 DUAL-FUEL-PROPULSION EFFECT ON SINGLE-STAGE VEHICLE'S DRY MASS



F-4 FUEL REDUCTION OF DRY MASS FOR TWO-STAGE VEHICLE



sures. Higher pressures will probably require advanced cycles; and even at that, one study of technology improvements that would allow higher chamber pressures did not find the expected vehicle improvement. Gas-generator losses increase with chamber pressure. For staged-combustion cycles, pump-discharge pressure, turbine-inlet temperature, and cooling requirements increase with chamber pressure. The designer has at least one unexploited way out of this bind. An advanced cycle with two combustion chambers at different pressures may allow an increase in pressure in the higher-pressure chamber by using power from the fluids of the lower-pressure chamber. The so-called dual-expander engine uses this scheme (F-2).

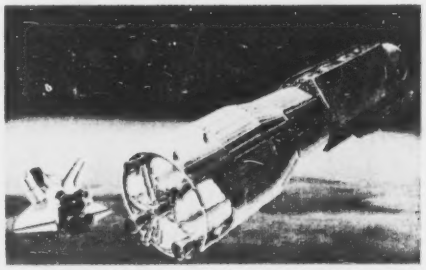
After optimizing combustion-chamber pressure, the designer may elect to see what improvements can be obtained from an extendable nozzle. Many concepts have been proposed, from translating cones to folding petals. Some are usable at low altitude in the stowed position, and some require the nozzle to be extended at ignition. An aerospike nozzle, with its free boundary, allows the nozzle effective exit-area to vary ideally with atmospheric pressure. Unfortunately, the combustion chambers for such concepts must be spread around the nozzle perimeter, which results in additional throat length and more cooling requirements. Vehicle-integrated nozzles should be considered, as Rudi Beichel proposed in his June 1975 *A/A* article. Flaps above and below the engines can vary expansion, or nozzles with circular throats around a vehicle surface can give an aerospike effect.

Changing the effective throat area of the nozzle, rather than the exit area, can also provide altitude compensation. The dual-expander and dual-throat and split-combustor aerospike engines use this approach by shutting off several of the combustion chambers, and letting the remainder use the entire exit area. The fact that this tactic reduces thrust at higher altitudes does not present a problem, since it is necessary to limit vehicle acceleration anyway.

Altitude compensation must be addressed before advanced vehicles can be developed. Both engine and vehicle studies are needed to compare the relative merits of the options. In some cases, experimental testing will be required.

High-Pressure Engines: Future Earth-to-orbit vehicles may well use hydrocarbon fuels in high-pressure engines, rather than hydrogen, or possibly tripropellant engines, which take advantage of the favorable characteristics of hydrogen to improve an engine that gets most of its thrust from hydrocarbon. The engines being considered have combustion-chamber pressures about equal to that of the SSME (3,000 psia).

From the vehicle standpoint, hydrocarbon fuel provides two main advantages over hydrogen: greater density, allowing the vehicle to be smaller and lighter, with smaller engine components, and requiring less pump horsepower for a given thrust; and less pressure loss, because the denser fuel increases thrust per unit throat area. Several studies have shown the value of hydrocarbon propulsion for advanced Earth-to-orbit vehicles, particularly for a recoverable liquid-rocket-booster derivative (replacing the current solid-rocket boosters) of the Space Shuttle. Life-cycle costs for the liquid-rocket boosters would be nearly twice as high with hydrogen as with hydrocarbon fuel, per recent study.

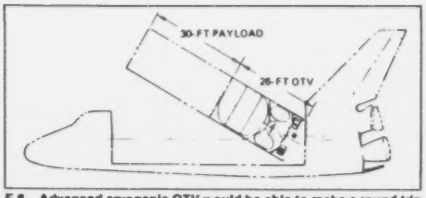


F-5 **Advanced storable-propellant stage** for placing 12,000-lb payload in GEO requires several key technology advances, such as development of small high-speed turbopumps.

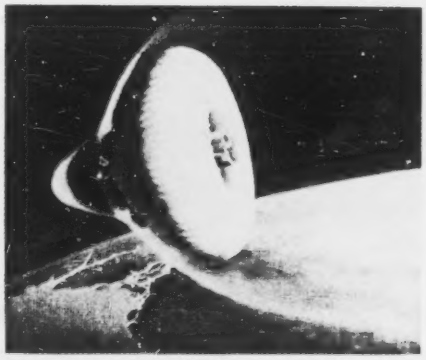
On the other hand, hydrogen provides higher specific impulse. Combining high-density and high-specific-impulse fuels can yield a more efficient vehicle than with either fuel alone, as Robert Salkeld has shown in his March 1974 *A/A* article.

Completely new Earth-to-orbit vehicles will be developed some time in the distant future. When these advanced vehicles will be required will depend upon many factors (e.g., traffic growth and the development of a liquid-booster Space Shuttle derivative). Prospective development of these vehicles should influence today's rocket-engine research.

Two concepts currently favored would benefit from advanced hydrocarbon engines. The first, a single-stage, vertical-takeoff vehicle could deliver a payload similar to, or somewhat smaller, than that of the Space Shuttle. F-3 shows that an optimum dual-fuel vehicle would have a dry mass of 94,000 kg. The vehicle using only hydrogen fuel, shown at a hydrocarbon propellant fraction of zero, would have a dry mass of 119,000 kg—over 25% greater. The second concept, a two-stage parallel-burn vehicle, likewise has more dry mass (about 12% more)



F-6 Advanced cryogenic OTV would be able to make a round trip to GEO with 16,000-lb expendable or 5000-lb reusable payload.



F-7 Concept of aerobraked OTV using an inflatable "ballute" would require engine throttling from full thrust down to 5%—a major R&D challenge.

using just hydrogen fuel than the minimum obtainable with hydrocarbon propulsion (F-4).

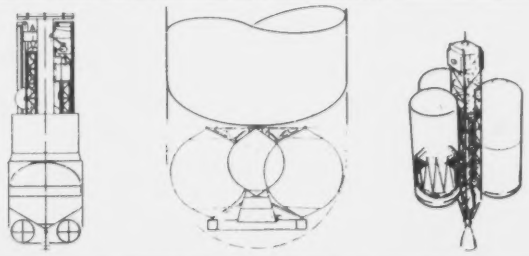
Based on the vehicle results just discussed, future efforts should include high-pressure hydrocarbon fuel engine research. Of particular interest are preburners and gas generators with hydrocarbon fuel (both oxygen-rich and fuel-rich). Cooling with both hydrocarbon fuel and oxygen needs to be considered. Studies should complete the data base for various cycles. Actually, a whole family of engines with two combustion chambers at different pressure should be considered.

Unquestionably, advances in liquid propulsion can improve future Earth-to-orbit vehicles. For advances to be ready when needed, however, R&D should be backed *now* with more money in a well-defined and consistent program.

Orbit-Transfer Vehicles (OTVs): Many future missions will require advanced OTVs. Spacecraft to be transferred from LEO to GEO will go up in size from the current 5,000 lb to more than 10,000 lb by the late '80s. For the '90s, missions with round-trip capability both to service satellites at GEO and for manned sorties call for vehicles weighing up to 25,000 lb.

Recovering the OTV may be cost-effective for some missions and is mandatory on manned sorties. Reusability also requires rapid turnaround techniques, probably based on design forethought and

F-8 ALTERNATIVE CRYOGENIC OTV CONCEPTS



	LOW THRUST	AFT CARGO COMPART	SPACE BASED
PURPOSES/ BENEFIT	• GENTLE ACCELERATION FOR LARGE SPACE SYSTEM • LARGER SPACECRAFT, FIX IN LEO	• MINIMIZES ORBITER-OTV INTERFACES • MORE PAYLOAD SPACE AVAILABLE	• ELIMINATE TRANSPORTATION OF OTV TO AND FROM ORBIT • MORE EFFICIENT TRANSPORTATION
UNCERTAINTY	• TOROIDAL LIQUID OXYGEN TANK • SMALL HYDROGEN/ OXYGEN PUMP-FED ENGINE	• SEVERE THERMAL/ACOUSTIC ENVIRONMENT • IN-FLIGHT ASSEMBLY TO SPACECRAFT	• SPACE MAINTENANCE • EXTENDED SPACE EXPOSURE
FUTURE	• LSS ARE "NEXT GENERATION." • COMBINE FEATURES IN BASIC OTV	• NEEDS FURTHER CONCEPTUAL STUDY	• NEXT GENERATION; INTEGRATE TRANSPORTATION WITH SOC STUDIES

automated monitoring of component "health." Ideally, a reusable OTV should be designed for man-rating from inception, allowing for increased margins of safety, built-in backups, and alternate modes of safe operation.

As NASA proceeds with its next probable major initiative—permanent occupancy of a space station in LEO—space-based rather than ground-based OTVs will evolve. Space-basing will evoke new design and maintenance concepts.

Two propellant combinations are of interest for future OTVs: Earth-storable nitrogen tetroxide/monomethylhydrazine (NTO/MMH) and cryogenic LOX/hydrogen. The latter offers higher performance but is limited to missions of only a few days' duration because of propellant boiloff. NTO/MMH better suits missions requiring space residence for months or years. Advanced Earth-storable-propellant OTVs are of particular interest to the USAF. They should achieve operational status in the late '80s; advanced cryogenic OTVs are not expected to become operational until the mid-'90s.

Both NASA and the USAF are investigating storable-propellant stages employing NTO/MMH. Although toxic and corrosive and lower in specific impulse than cryogenic oxygen and hydrogen, these propellants have two important advantages. They are denser, thus allowing for a more compact stage, and they do not require a complex and costly thermal-control subsystem. Since there are no propellant boil-off losses, a storable-propellant stage is attractive for missions that require long-term orbit maneuvering. This storable propulsion technology suits a number of vehicles, including a small, quick-reaction transfer stage that could be used with such new launch vehicle concepts as the "Advanced Military Spaceflight Capability (AMSC)."

An advanced pump-fed storable stage (F-5) could place a 12,000-lb payload into GEO. This stage would employ four pump-fed engines providing 3750 lbf each, yielding a high specific impulse by operating at a chamber pressure of 1,400 psi with a nozzle area ratio of 400:1. The 340-sec I_{sp} would be about 10% higher than the yield of today's pressure-fed storable bipropellant engines. The 6,000-lbf Shuttle pressure-fed OMS engine delivers an I_{sp} of only 313 sec due to its low chamber pressure of 125 psi and nozzle area ratio of only 55:1.

The high-density I_{sp} associated with the pump-fed storable stage permits a more compact propulsion system (8.5 ft long) and therefore longer payloads in the Shuttle cargo bay than can be achieved with a cryogenic stage. But it cannot be brought into being without several key advancements: high-chamber-pressure NTO regeneratively cooled thrust chambers, small high-speed turbopumps (gas-generator cycle), low-cost light tankage and propellant-acquisition systems, a low-cost reliable tank pressurization system, and high propellant-mass-fraction stage. The USAF will be pursuing these technology developments over the next several years. The sooner this work can be accomplished, the better for advanced system development.

T-1 CRYOGENIC LIQUID PROPULSION ADVANCES NEEDED FOR OTVS

Advances	Impact	Benefit
A. Main engine		
Increased I_{sp}	High pressure, more expansion	100 lb payload per 1 sec I_{sp}
Low-thrust concepts	Pumps, injectors, heat exchanger	Propellant settling, or low acceleration
Light weight	Use of composite materials	1 lb payload per 1 lb engine weight
Reusability	Monitoring and checkout equipment	Saves operating costs on some missions
Man-rating	Reduced stress; redundancy	Required for manned sortie
B. Propellant supply		
Reusability	Propellant tanks checkout	Save operating costs
Reduced vehicle length	Torus tank (dynamics)	Key to accommodate long payload
Zero-gravity propellant management and transfer	Acquisition, mixing, venting, insulation and heat exchangers	Enable mission versatility and resupply on orbit
Increased storability	Reduce cryogenic boiloff	Increase space residence

Unlike the storables, cryogenic propellants—liquid oxygen and hydrogen—are nontoxic, noncorrosive, and up to 50% higher in performance. (A 1 sec gain in I_{sp} is worth about 100 lb of payload on round-trip missions from LEO to GEO).

The Space Shuttle Centaur under development represents the state of the art in high-energy upper stages. It can deliver 14,000 lb to GEO, using some 46,000 lb of H_2 and O_2 at an I_{sp} of 446 sec.

A new cryogenic OTV can be based on a growth Shuttle with 75,000-100,000 lb of cargo carrying ability. As an uprated version of the vehicle using dual OTV engines (see F-6) it would be able to make round trips to GEO, either manned or unmanned, with 12,000 lb of return weight. It would employ such new technology as a toroidal O_2 tank, an advanced expander-cycle rocket engine, and possibly aerobraking, along the lines depicted in F-7, which shows an inflatable "ballute" and variable low retrothrust for return to LEO to rendezvous with the Shuttle or a space station. Development of an engine for this approach will be particularly challenging because of the wide range of throttling required: from full thrust down to 5%.

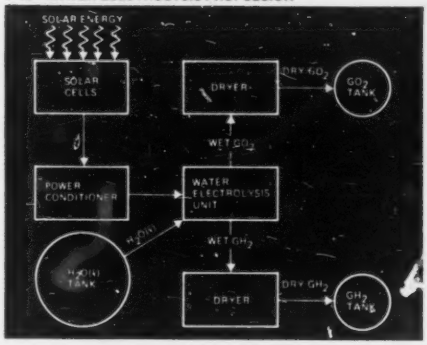
F-8 outlines several other cryogenic OTV concepts being considered by both NASA and the USAF for low-thrust vehicles to transfer very large space systems from the Shuttle to higher orbits. Spacecraft

T-2 LOX/ETHANOL VS. NTO/MMH FOR ORBITER AUXILIARY PROPULSION

System	LOX/ethanol system	NTO/MMH system[a]
OMS RV, fps	600	500
OMS and Aft RCS		
Wet weight,[b] lbm	15,900	17,200
Dry	1,880	2,100

[a] Existing Orbiter OMS and aft-RCS baseline.
[b] OMS RV = 500 ft/sec.

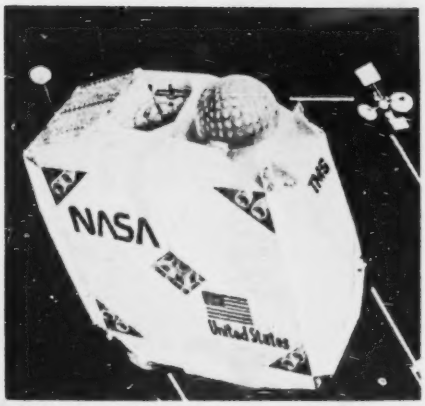
F-10 WATER-ELECTROLYSIS PROPULSION



would be transferred very gently, at low acceleration, allowing transport of very-low-mass structures by employing low thrust (about 500 lbf). They would use cryogenic propellants to maximize payload. A toroidal O_2 tank would reduce OTV length, leaving more space for stowing the spacecraft payload. An optimized low-thrust OTV has many desirable features, but lack of funding may dictate a high-thrust vehicle and significant weight penalties.

Future requirements for increased performance, return trips, and manned sorties will require continued improvements in cryogenic-propellant storability, management, and transfer; use of capillary devices to deliver propellant for restarts; and large and low-mass reusable cryogenic-propellant tanks and toroidal O_2 tanks (see T-1).

Auxiliary Propulsion: Auxiliary propulsion has been a backwater of technical development. Systems used today on various spacecraft, including the Shuttle Orbiter, evolved over the last twenty years and in the main use only two types of propellant—the Earth-storable bipropellant NTO/MMH and monopropellant hydrazine. In both cases, the systems are pressure-fed, with operating chamber pressures in the range of 200 psia or below. These systems have satisfied requirements to date and provide a wide base of flight-qualified hardware; but future missions will demand new operating regimes, higher I_{sp}, much greater total impulse, and longer



F-9 **Teleoperator Maneuvering System,** designed for compact Shuttle carriage, introduces a new level of variable-throttling performance objectives.

life; and they will place a greater emphasis on design safety, toxicity and corrosiveness of propellants, contamination control, refurbishment, accessibility for replacement, and operating costs.

For many satellite applications, hydrazine monopropellant systems will continue to be used because of their inherent simplicity, high reliability, and relatively low hardware cost. Their primary disadvantage—low I_{sp} (in the range of 230 sec)—can be partly overcome by electrically heating the hydrazine decomposition exhaust products to boost I_{sp} into the 300-sec range. (The Intelsat V communications satellite already applies this tactic.) Also, a catalytic reactor can precede the augmentation heat exchanger. This year, Satcom, G-STAR, and Spacenet communication satellites will introduce such augmented systems.

Qualified engines for Earth-storable bipropellant reaction control system (RCS) applications are currently available at the 870- and 25-lb-thrust levels from the Space Shuttle program and at the 100- and 5-lb-thrust levels from the INSAT and Systems Applications Laboratory (SAL) programs. Future applications, such as new geostationary satellites and space platforms, show a requirement for even lower levels. To meet this need, several companies are engaged in bipropellant thruster development in the 0.5-1.0-lbf range. Such low-thrust attitude-control thrusters can be integrated with the larger thrusters used for orbit maneuvering or transfer to achieve greater packaging efficiency and lower cost. Substitution of hydrazine for MMH in existing bipropellant hardware systems has been under evaluation. This would permit using the hydrazine as a

monopropellant from the fuel side of the bipropellant system for reaction control (RCS). The velocity-increment thrusting would be bipropellant (i.e. N_2O_4/N_2H_4). Spacecraft needing extremely low thrust (below 0.5 lbf) from the RCS would especially benefit from this scheme.

Improved Shuttle Orbiter auxiliary propulsion would reduce STS operating costs. One study explored alternative propellants such as LOX/hydrocarbon or LOX/hydrogen in both the orbital maneuvering subsystem (OMS) and RCS. It concluded that better performance could be obtained with a somewhat more complicated auxiliary propulsion system using LOX/ethanol. T-2 compares performance of the current NTO/MMH and the envisioned LOX/ethanol.

The LOX/ethanol system would feature a single turbine to drive both the OMS fuel and oxidizer pumps; separate electric pumps to resupply the propellant accumulators used to feed the RCS primary and vernier thrusters. Liquid propellants would be used for the OMS engine and gaseous oxygen and liquid ethanol for the RCS engines. Heat capacity of the liquid ethanol gasifies the oxygen for the RCS engines. Although the pumps and thermal conditioning increase system complexity, the LOX/ethanol propellants are low in cost, nontoxic, noncorrosive, and will substantially lower operatinal costs. To gain these benefits we must develop the required pump and engine technology.

Wide-range throttling systems are expected to be in greater demand for a variety of space maneuvering involving manned and unmanned movements between the Shuttle, a space station or space platforms, and other spacecraft. Military interceptors will need both pulse-modulated and wide-range, variable-thrust auxiliary propulsion capable of attaining very high response and producing large variations in acceleration.

The NASA Teleoperator Maneuvering System (TMS, F-9) has been optimized for minimum length in the Shuttle cargo bay. It uses eight throttling hydrazine engines. In the planning are growth versions for Earth-storable bipropellant engines capable of thrust variations from 113 to 35 lb.

Future satellites in general, and communication satellites in particular, will require auxiliary propulsion with longer life (over 15 years) and lower cost. Thus the effects of long-term compatibility as well as very high number of operational cycles (mechanical, thermal and pressure) must be better understood. Technology programs are needed to gain more data in the following areas:

- Fracture mechanics of propellant-feed-system materials after long propellant exposure and of thrust-chamber materials after many thermal/pressure cycles.
- Propellant characterization to determine the relation of contamination and degradation to storage specifications, including cleanliness and effects of minor constituents.
- Thermal, pressure, and cycle fatigue in terms of cracking or loss of thrust-chamber materials and coatings.
- Plume contamination for various propellant combinations and physical arrangements.
- Monitoring equipment for leakage and wear-out detection, and propellant depletion to support autonomous operations.

Higher-energy propellants can improve performance. High-density, fluorinated oxidizers with amine fuels (I_{sp}, 460 sec) particularly interest designers for OTVs, space-station elements, and laser weapon systems. While much engine experience has been gained with fluorinated oxidizers, additional development is needed to meet operational flight needs when they are defined for future missions.

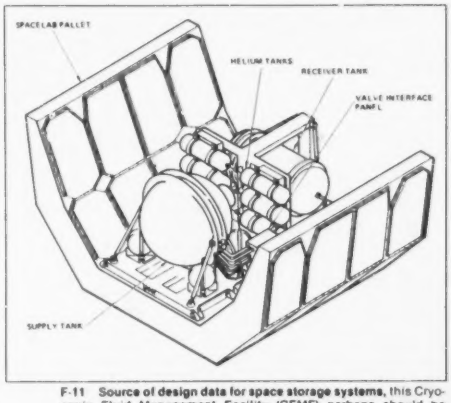
Oxygen and hydrogen will see increasingly greater application for auxiliary propulsion. Pulse-modulated auxiliary propulsion systems will most likely employ gaseous O_2 and H_2 to gain important weight and volume advantages. NASA space-station studies indicate advantages for engines that operate in either gaseous- or liquid-propellant modes. Thus, a 30-lbf gaseous-propellant engine could also be used as a 200-lbf liquid-propellant engine. Using the higher thrust for OTV functions or more rapid maneuvering, and the lower thrust for attitude control and positioning, offers possibilities. But these flight-type O_2H_2 engines using either all gas or gaseous/liquid propellants for auxiliary propulsion must yet be developed.

Thruster technology for very small gaseous O_2/H_2 engines has reached an advanced state and offers extremely small impulse bits (0.001 lb-sec), but much effort will be needed to develop flight-qualified engines. For long-life space systems with large power-generation ability, use of H_2 and O_2 derived from water by electrolysis appears to offer advantages. The water-electrolysis propulsion system (F-10) has already undergone extensive development. Gaseous propellants can also be liquefied at a space station for use in propulsion, emergency power, and life-support subsystems.

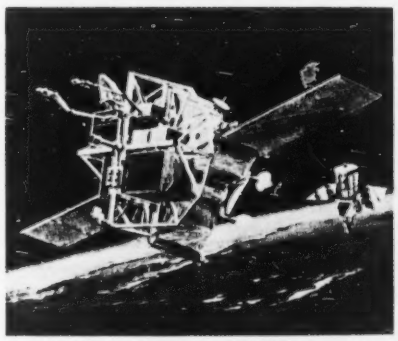
Planetary-Spacecraft Propulsion: Planetary spacecraft have increased in size and thus performance requirements to meet ambitious mission concepts. The Galileo orbiter embodies a propulsion velocity increment (ΔV) of 1700 m/sec —an order of magnitude greater than the early

Mariners. Spacecraft flight times have increased from a fraction of a year to over five years (the Voyager mission). Work in this field has long been devoted to obtaining the necessary performance, and now needs to concentrate on cost optimization. In view of the limited funding available for the immediate future, the major emphasis of the planetary programs will be on low-cost missions.

The current Mariner Mark II (MM II) study seeks cost reductions through multimission spacecraft design. Missions under consideration for MM II spacecraft include Mars and Saturn orbiters, a Titan flyby, comet and asteroid rendezvous, and a comet-sample return. These missions require Galileo-class NTO/MMH propulsion systems, but need supporting technology programs to reduce cost and contamination and to increase reliability. Contamination of spacecraft optics, low-temperature sensors, and heat-rejection systems by the propulsion system is not adequately understood, requiring study of the backflow region, plume and spacecraft structure interactions, and deposition of exhaust products on spacecraft surfaces.



F-11 **Source of design data for space storage systems,** this Cryogenic Fluid Management Facility (CFMF) perhaps should be pushed for earlier launch than the scheduled 1989 date.



F-12 **Teleoperator Maneuvering System (TMS) with remote operations service system gains in cost-effectiveness** by on-orbit propellant resupply, an objective of technology developments.

Manufacturing propellants in space (e.g., oxygen from Martian carbon dioxide) can increase the performance of sample-return and planetary cruiser missions. Long-life, low-mass active-thermal-control systems for liquid-hydrogen storage will also raise mission performance. Such a cryogenic pump-fed system would deliver twice the payload to Neptune as a comparable pressure-fed Earth-storable propulsion system.

In summary, much of the necessary technology is common to the space station, OTVs, and space-based weapons. Coordination of programs will aid efficient technology development.

Space-Based Fluid-Management Systems: Space-based propulsion and reactant storage will require new techniques for storage, resupply, and maintenance to achieve cost-effectiveness in the anticipated long-duration operations. Integrating propulsion and reactant storage brings packaging and weight advantages. The longest subcritical (liquid) cryogen storage in space has been 8 hr and 22 min (Titan/Centaur TC-5 Extended Mission). Mission models covering the next twenty years include on-orbit stay times of five years and longer.

Effective thermal control, integrated with effective low-*g* fluid management will be the key to longer storage. Systems have been developed for storable propellants, but need verification and possible further development for cryogens. Either boil-off in a thermodynamic vent system or active refrigeration of the storage tank and its surroundings can serve thermal-control needs; but the reliability of low-mass refrigeration systems now limits missions.

Other technology needs include long-life insulation with minimized contamination and degradation, tank supports and penetrations to minimize heat leaks, low-*g* gauging systems, low-volume (flow-rate) cryogenic pumps, long cycle life for valves, and reliability of electronics. System issues include development of a protective enclosure for the cryogenic storage system to prevent damage from space debris and to allow fully automated on-board inspection, checkout, and servicing.

The Cryogenic Fluid Management Facility (CFMF, F-11) being pursued by NASA—a reusable

Shuttle test-bed—will use liquid hydrogen as the test fluid to conduct experiments on thermal protection, liquid position control (fluid acquisition), tank-pressure control, fluid transfer and resupply, and gauging of fluids in low-*g* flight. CFMF is not scheduled to be flown until 1989. The growing interest in on-orbit storage and need for design data suggest the need for an earlier flight.

Resupply lowers life-cycle costs and minimizes the use of expendable systems. Cost studies since 1970 clearly show the economic benefits of on-orbit servicing compared to ground refurbishment or expandable systems. Refueling of a space-based OTV has been proposed as one important space-station function. Resupply might make use of an aft-cargo carrier (ACC) on the Shuttle's External Tank (ET). This ACC would have catch tanks for scavenging residual ET liquid hydrogen and LOX. Depending on the Shuttle payload weight, the catch tanks could be partially full during launch for in-orbit transfer and later scavenging, or they could be empty for scavenging from the ET only. At a space station the propellants would be transferred to long-duration storage containers. Alternately, the catch tanks could be designed for long-term storage and merely cascaded together at the space station for OTV servicing.

Fluid-resupply approaches that have been proposed for both Earth-storage and cryogenic propellants include gravity transfer (tanks rotated, with supply and receiver tanks on opposite sides of the center of rotation), positive expulsion (primarily usable with storable propellants and small tank sizes with limited reuse), nonvented fill (to resupply a blowdown system or a pressurized system vented to a lower pressure with no condensable gas), and capillary fluid management (using surface-tension properties to position the liquid, permitting vapor venting with a gravity field). Fluid-resupply technology needs include remotely operated nonleak transfer-line disconnects, mass gauging for continuous system monitoring during the fill process, standard carrier-plate interfaces, connectors to mate with Shuttle-contained resupply servicing systems, and long-cycle-life leaktight valves to prevent propellant migration (e.g., to pressurant tanks).

Repair or replacement of components and subsystems helps meet life requirements and lessens the need for redundancy. Filled propellant tanks as modular replacements fall in this category for the smaller propulsion systems. A key issue is autonomy vs. man-in-the-loop operations. The Solar Maximum Mission spacecraft will be repaired by an astronaut using the manned maneuvering unit. A teleoperator maneuvering system (TMS), on the other hand, will retrieve satellites and return them to the Orbiter for servicing or Earth return. When mated with service modules, such as the Remote Operations Servicing System, TMS will provide routine or contingency on-orbit servicing, maintenance, and reconfiguration operations while remotely controlled from a ground station. Resupply of the TMS propellants increases its cost-effectiveness. In all this work, technological advancements in on-orbit storage and resupply—a key to cost-effective space operations—need to be pressed for timely incorporation into flight systems.

Concluding Remarks: Since the advent of Sputnik in 1957, the United States has repeatedly emphasized its policy to maintain world leadership in space technology. Our nation continues to lead the world in rocket propulsion, but the systems now in use are products of R&D programs begun over a decade ago. We have no major technology programs in active support of advanced propulsion concepts. The AIAA Liquid Propulsion Technical Committee (TC)—through its own studies, its assessment of planning activities within NASA, DOD, industry, and participation in reviews of USAF space-technology (MSSTM) requirements—concludes that *future programs have a common need for advanced-propulsion-system development to realize their objectives in a cost-effective manner.* This requires an adequate federally sponsored R&D program committed to optimal liquid-rocket systems insuring minimal risk technology readiness.

Five basic categories of liquid-propulsion systems require technology advancement:

- Launchers and boosters.
- High-performance orbit-transfer and planetary-injection systems.
- High-performance space-storable maneuvering systems.
- High-performance auxiliary systems.
- Long-term space fluid storage, resupply, and maintenance.

Without a renewal of liquid-propulsion technology, the nation will not achieve it needed goals of performance and cost-effectiveness in coming space systems. It is in the nation's interest to maintain and expand the existing technology base. Further, because advanced liquid-rocket systems require lengthy development, the Committee finds an *immediate* need for technology programs that will raise mission performance and simultaneously cut launch costs. A small continuing investment throughout the 1980s will greatly reduce the development costs of future space systems. The federal government, as the principal user of space systems, should begin the investment now.

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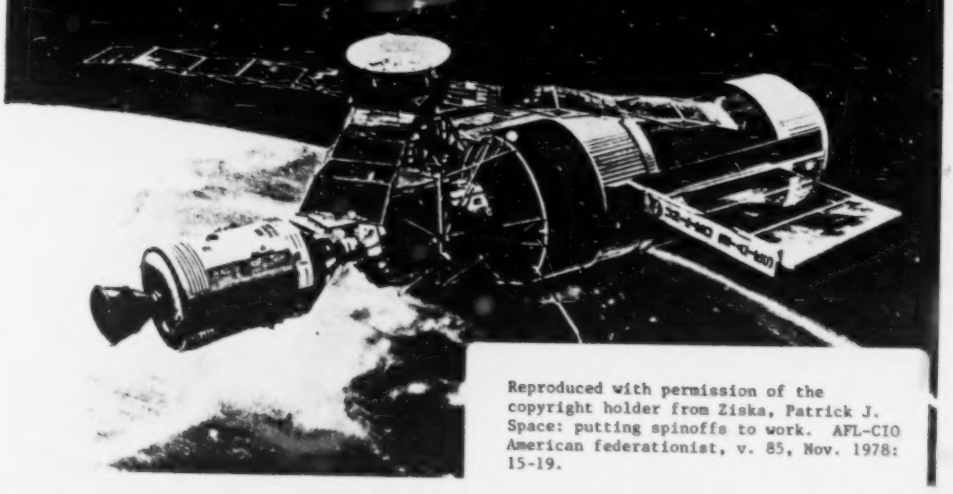
Space: Putting Spinoffs to Work

by Patrick J. Ziska



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On July 20, 1969, humankind broke through the cocoon that had confined it to one planet for 4.5 million years. On that day we humans stopped being an earthbound colony and started becoming space-destined butterflies. On that day two Americans walked on the surface of the moon, while millions of other Americans watched with awe in their homes. And on that day the once wild fantasies of science fiction began being translated into the realities of practical science applied.

For many thousands of American workers, the moon walk was of special interest and unique pride. They and their skills had helped make the moment possible. Their contributions had demonstrated to even the skeptical that as the future becomes the present, science and craftsmanship have found a way to catch up with what had been space fiction.

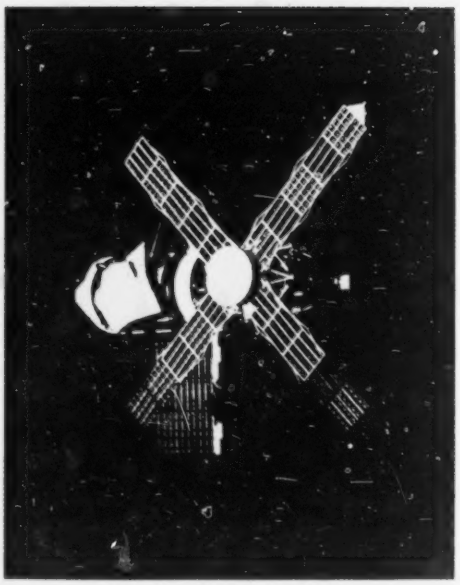
In the years since that historic moon mission, America's fascination with the final frontier propelled space adventure into almost a second national pastime. For instance, interest in space fiction, which somehow seems to cease being fiction and start being fact with the passage of time, has made the movie Star Wars into the biggest box office attraction ever, grossing $220 million in its first year of release. The sale of Star Wars memorabilia such as T-shirts and bubble gum has grossed another $200 million. And when space fans are not watching such adventures, they are reading about them. This year Americans spent $45 million on space books, fact and fiction, compared with only $1.5 million in 1968.

While Americans have made space adventure a hobby, more than 100,000 workers have quietly nudged space technology from adventure to practical application. These workers, members of nearly every U.S. union, are part of the team that has brought us from Explorer I to the moon. Now these skilled workers are moving the nation closer to the final frontier with their work on space labs, space freighters and—sooner than many now believe—to space colonies.

In the first two decades of space technology since America's first satellite, Explorer I, went hurtling into space, this team has contributed both to the nation's economy and its technology.

Dr. Robert A. Frosch, administrator of the National Aeronautics and Space Administration (NASA), de-

PATRICK J. ZISKA is an associate editor of The Machinist.



scribed some of the contributions of organized workers this way: "This is the team which took us from Sputnik to the moon in an incredible dozen years; which so precisely soft-landed the Viking spacecraft on Mars; which has dispatched the Pioneer and Voyager probes on their long planetary explorations; which created the High Energy Astronomy Satellites whose sensors are investigating the far universe; and which is developing the Space Transportation System, throwing the door to space wide open for the decade of the 1980s and beyond."

Frosch notes that NASA spends more than 80 percent of its budget on labor intensive contracts and current programs employ more than 100,000 workers.

But the jobs impact is only one factor in the nation's ongoing space program. Equally important is the maintenance of U.S. technological leadership in the world community. Space research also has helped improve the current generation of commercial aircraft for the nation's travellers and is laying the foundation for the more advanced planes now on the drawing board to replace a generation of aircraft growing old. This technology will enable aerospace companies to advance their technology to meet the needs of the nation's airlines for an estimated $75 billion in new planes in the next decade.

Besides these obvious benefits, thousands of indirect benefits from secondary applications of space technology occur.

These benefits, or spinoffs as they are called by NASA, range from simple conveniences to major systems that help solve critical problems. They can save the seriously ill from death. They include satellites which beam sports and cultural events from Europe to our homes. They include life-saving, two-way communications transmitting a heart attack victim's cardiogram from an ambulance to a hospital. NASA calls these spinoffs a "tale of technology twice told."

Space technology has been transferred to medicine, transportation, public safety, energy and pollution solutions, construction, communications, industrial and agricultural processes, sports and recreation and to nearly every avenue of everyday life.

And within these broad categories, there have been thousands of individual spinoffs.

Critics of the space program point out some of the more frivolous applications such as the crystal candy which when dissolved in water forms a gravity free beverage.

But they either ignore or are unaware of the many more serious spinoffs. In the field of medicine, space technology has provided life saving equipment aiding humanity from birth to brushes with death.

The technology developed primarily to heat faceplates for pressure units in space are now adapted and used in post-delivery care of infants born prematurely or with respiratory problems. Automated blood pressure measurement, another spinoff, enables untrained personnel to monitor ill relatives and friends. Space communications systems aid patients enroute to hospitals after heart attacks and other medical emergencies, saving vital time particularly when the scene of the emergency is remote from the hospital. Similar systems enable nurses to monitor large numbers of patients in intensive care units.

Heated transparency technology, originally developed for use on space vehicle faceplates and cockpit canopies, is now working to save burn patients discomfort and more serious complications. An important factor in burn treatment is keeping the patient warm to counter hypothermia, a state of low body temperature characteristic of burn patients. Sheets and blankets cannot be used and until the development of the special canopy, it was necessary to suspend coverings over hoops encircling the patient's bed. Even so, burn victims complained of cold. The problem involved more than discomfort. Shivering uses up large amounts of energy needed to fight infection and renew damaged cells. The Apollo Radiant Warmer, an over-the-bed canopy, provides the warmth without the discomfort or danger of infection or unwanted weight loss caused by excessive shivering. The heat is provided by emitting uniform, controlled radiant heat to the patient.

Space technology applied to medicine is used in

scores of other ways, to analyze X-ray films, in hearing aids and testers and in other areas of preventive, diagnostic and curative medicine.

Workers exposed to microwaves have a new tool to detect microwave radiation hazards. NASA technology has now made commercially available a new, inexpensive device to measure the radio emissions of extremely high frequency. Thus workers can determine if they are being exposed to more than the allowable threshold set by the Occupational Safety and Health Administration (OSHA).

Secondary applications of safety devices first used in space cover everything from fire detection equipment to heat resistant paint to life rafts which cannot be overturned. Because of safety features on manned spacecraft, homeowners, miners and other workers are enjoying sophisticated early-warning fire detection sensors. Space technology also provides other danger detectors including one to "read" carbon monoxide levels. It has also developed an instrument which protects against electrical shock in home and workplace.

Home protection is improved by yet another detector, this one to pinpoint an intruder. Still another space development with life-saving potential is the satellite search and rescue system, a method of monitoring and locating distress signals from downed aircraft or troubled ships. This package picks up beacon signals, measures their direction of source and relays it to a rescue coordination center.

Space scientists were not surprised by last year's water shortage on the West Coast. Landsat photos had shown the watershed inventory was dwindling well before it happened. Landsat is an earth survey satellite whose sensors detect light waves reflected from the earth. These waves are then translated into images that allow analysts to view the surface of the globe in new perspective. Large portions of the earth may be studied at one time and terrestrial features that cannot be seen by the human eye are studied for changes of earth conditions. Thus they can take watershed inventories, study changing ocean conditions and forecast conditions for shipping, fishing and oil industries. Such satellites can also foresee other changing earth conditions such as imminent earthquakes and warn of impending hurricanes and tornadoes. The list of applications in this area is lengthy and growing. It includes pollution detection, plotting changes in ecology after disasters such as forest fires and improving the accuracy of maps.

Space technology has also provided for a better leisure life. Fans of the Detroit Lions, for instance, do not worry about game day weather. Their Pontiac Stadium has a domed, air supported, fabric roof that admits light but protects the playing field and patrons from the elements. The 80,000-seat stadium is the world's largest fabric-covered structure, and aerospace technology played an important role in its construction. The Detroit "cover" cost $10 million and enabled the city to build its stadium for under $56 million compared with a cost of $168 million for the Superdome in New Orleans. The flame resistant, all-weather material used in Pontiac was a fabric adapted from Appollo astronauts' space suits.

Perhaps the most vital potential benefit from space technology is providing an energy deficient earth with electricity from the sun.

The key to making this proposal reality is the solar power satellite. While other sources of energy—nuclear, coal and other fossil fuels—are being mined, the nation is looking toward the sun as a potential energy donor.

By harnessing its rays in space, and transforming this power into electricity useable on earth, the nation could tap a power as durable as humankind. The potential for accomplishing this feat is the solar satellite, a spacecraft the size of a small city. The satellite would be able to produce twice as much useable power as that generated by the nation's largest hydroelectric dam at Grand Coulee on the Columbia River in Washington state. Forty-five such satellites could match the present total electrical generating power of the nation. If they were in operation, oil, coal and their derivatives would be freed for other uses. As envisioned by space planners, the satellites would be deployed 22,000 miles above the earth's equator. They would work by transforming the sun's rays into electricity and convert this to microwaves which would be beamed to large antennas on earth. These antennas would reconvert this power, providing electricity for the nation's power grid.

Experts calculate that the initial cost of such a space powerhouse would be about $7.6 billion in 1974 dollars. Each subsequent satellite would cost less. The total investment could be repaid with about 60 satellites.

Before these satellites can be built and used, questions about ecology and practicality must be answered. Although many aerospace companies have studied the feasibility of solar satellites and offered plans on how to construct them, much research is still needed. That is why some AFL-CIO unions pushed for legislation in the 95th Congress to appropriate and authorize $25 million for research and development of a satellite system. Among the questions such research would have answered was whether the microwave transmission of energy could be accomplished safely. The bill passed the House, but died before the Senate could act on it. The same bill will be introduced in the 96th Congress.

Obviously, if research shows that satellites are economically and environmentally feasible, the next question would be where to build them. Such spacecraft, measured in miles rather than feet, cannot be launched like an Apollo mooncraft. The solar satellites would have to be constructed either in low earth orbit for later shipment to the higher orbit, or would be constructed directly at the higher orbit site.

Whichever way were chosen, a space freighter

would have to convey the personnel and material. That's where the space shuttle would come in.

The development of the shuttle marks what many observers consider the second space era, less glamorous than the walk on the moon, but much more practical. The second space era has been likened to the discovery of the wheel. The era will highlight space transportation, leading to energy pumping satellites and space colonies.

The past two decades brought the feat of a man stepping on the moon as 500 million viewed it on television or listened on the radio. In the dawning second space era, man will transport laboratories, satellites and colonies (and their colonists) and many more millions will benefit.

In this way, the space industrial society will begin, marking what may be the most significant wonder in human history. The bridge that will carry us to this era is the space shuttle. Its first manned orbital flight is now less than a year away. The shuttle will carry a cargo or payload of 65,000 pounds. Its mission will be to deliver this payload into high earth orbit or into lunar or planetary trajectories.

This cargo will be carried in the shuttle's orbiter. The orbiter spacecraft is about the size of a DC 9 commercial jetliner. It weighs about 75 tons and measures 122 feet in length. The orbiter can carry, along with the cargo, a crew of seven, including scientific and technical personnel.

Because the orbiter will provide for a standard sea level atmosphere inside, any reasonably healthy space worker or other person can be a comfortable passenger. On the first missions, the orbiter will be able to remain in orbit for up to seven days. Then it will return to earth, be refurbished and be ready for another launch within 24 hours. Other shuttle components besides the orbiter are an external tank and two solid rocket boosters. The external tank contains the ascent propellant. Both the orbiter and the boosters are reuseable, the orbiter is good for at least 100 missions. The boosters, which burn in parallel with the orbiter's main propulsion system, are separated from the orbiter when the vehicle is about 24 miles high. Then the boosters are dropped by parachute into the ocean about 150 miles from the launch site at Kennedy Space Center. When the orbiter's mission of delivery to space satellites or maintenance of such satellites is finished, re-entry is made into earth's atmosphere. The orbiter is then landed with a horizontal approach and touchdown similar to that made by conventional aircraft. Workers are now swarming over the huge launch complex at Kennedy preparing for the next exciting chapter of space history. That launch is now scheduled for mid-September 1979.

The shuttle then will be more than just a space freighter. It will be used to retrieve payloads from orbit, to service and maintain satellites and to operate space laboratories. NASA officials also look toward the day when the shuttle will be carrying workers to space colonies.

As envisioned by Dr. Gerard K. O'Neill, professor of physics at Princeton, this could happen as early as the 1990s.

Several designs for permanent space stations already have been developed. One design calls for a station comprised of cylinder type modules. Eight of these modules joined together could accommodate a workforce of 50. One such module could easily fit into the cargo bay of the shuttle now being prepared for launch.

Our ability to put people into space and to maintain them there in good health began with the Apollo moon landing project. The Skylab project of the early 1970s extended the time limit for astronauts in space to three months.

According to O'Neill, the maintenance of life for "a time of as many months as would be necessary for a voyage to the asteroids, presents no problems which are new in principle."

The asteroids, thousands of small planets most lying between Mars and Jupiter, are rich in ores. If these asteroids could be mined, as futurists now propose, the earth could benefit with a 200-year supply of nickel and enough steel for many years.

Using the shuttle as the primary means of transspatial travel, much as the wagon trains were the first mode of trans-continental transport, O'Neill sees the possibility of traveling through space in "a tugboat and a string of barges. In space there is no drag," he says, "the tugboat would be needed only at the start and end of each trip, and during the long months of the orbit . . . could travel unmanned."

O'Neill also writes a scenario about a husband and wife living near the close of the 20th Century on a space colony. There they work and live, coming back to earth for periodic vacations.

In a "letter" back to friends on earth, O'Neill's space couple writes: "It's a comfortable life here. Fresh vegetables and fruit are in season all the time, because there are agricultural cylinders for each month of the year, each with its own day-length. We grow avocadoes and payas in our own garden, and never need to use insecticide sprays. Of course we like being able to get a suntan without ever being bitten by a mosquito. To be free of those pests, it's worth it to go through the inspections before getting aboard the shuttle from earth."

The fictional writer of the "letter" is a construction worker and his letter indicates that space colonies will have the same problems as earth communities. The need for space trade unions is apparent.

If, as O'Neill and many other space experts predict, workers will be living on space colonies by the year 2000, there may well be delegates from such exotic places as Space Colony Alpha at the 21st Century's first AFL-CIO Convention.

If that sounds farfetched in 1978, so did the concept of men walking on the moon when it was proposed 22 years ago.

98th Congress
1st Session

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POLICY AND LEGAL ISSUES INVOLVED IN THE COMMERCIALIZATION OF SPACE

PRINTED AT THE DIRECTION OF

HON. BOB PACKWOOD, *Chairman*

FOR THE USE OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE

SEPTEMBER 23, 1983

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LETTER OF TRANSMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, D.C., September 23, 1983.

DEAR COLLEAGUE:

The Committee on Commerce, Science, and Transportation and the Subcommittee on Science, Technology, and Space are pleased to submit this report on the policy and legal issues associated with the commercialization of space. Information in this report was originally requested of the Congressional Research Service by Senator Hollings.

This report is particularly timely given the decision by the President in March 1983, to pursue the transfer of the weather and land remote sensing satellites to the private sector and his May, 1983, announcement that the Government will facilitate commercial operation of Expendable Launch Vehicles.

The Committee and the Congress have approved legislation which would require Congressional participation in the implementation of any plan to commercialize these national assets. It is not the purpose of the legislation or the intent of the Committee to foreclose the options for commercialization; rather, there is a legitimate Congressional interest in the proposals such as to require timely and open participation in the decision process.

The commercial promise of space is being realized. Our first revolution is in communications; the next could be in materials processing or terrestrial observations, as examples. Government has led and continues to lead the research and development, but commercialization is primarily a private sector responsibility. We have not yet determined when, how or what governmental responsibility should be relinquished so that the public benefit will be optimized.

The report which we are releasing sheds additional light on the problems and issues of commercializing space activities. The effective resolution of these issues will be of major importance to our national security and economic well-being.

Cordially,

BOB PACKWOOD,
Chairman, Committee on Commerce, Science, and Transportation.

SLADE GORTON,
Chairman, Subcommittee on Science, Technology, and Space.

LETTER OF SUBMITTAL

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, D.C., July 20, 1983.

Hon. BOB PACKWOOD,
Chairman, Committee on Commerce, Science, and Transportation, U.S. Senate, Washington, D.C.

DEAR MR. CHAIRMAN: I am pleased to transmit a report by the Congressional Research Service, prepared at my request, evaluating the legal and policy issues involved in space commercialization.

One of the significant areas of continued U.S. international leadership is space. With the successful operation of the Space Shuttle, we now have a capability to utilize space on a routine basis. This will help lead the way to enormous economic and commercial benefits. As a Nation we must be prepared to pursue the opportunities in such areas as launch services, communications, remote sensing and materials processing.

In entering this new commercial era of space, we are likely to encounter various policy and legal questions. This CRS report should help the Congress and others indentify those questions and various options to deal with them. I hope this report will be made available widely.

With kindest regards, I am

Sincerely,

ERNEST F. HOLLINGS, *Ranking Democrat.*

Enclosure.

CONGRESSIONAL RESEARCH SERVICE,
THE LIBRARY OF CONGRESS,
Washington, D.C., May 12, 1983.

Hon. ERNEST F. HOLLINGS,
U.S. Senate,
Washington, D.C.

DEAR SENATOR HOLLINGS: Pursuant to your letter of January 17, 1983, we are herewith providing a study entitled "Policy and Legal Issues Involved in the Commercialization of Space." The report was prepared by Marcia S. Smith, Specialist in Aerospace and Telecommunications Systems of the Science Policy Research Division, and Daniel Hill Zafren, Specialist in American Public Law of the American Law Division.

We hope that this study will be useful to you in assessing the implications of space commercialization activities in your role as ranking minority member of the Committee on Commerce, Science, and Transportation.

If we can be of further assistance, please let us know. With best regards,

Sincerely,

GILBERT GUDE, *Director.*

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SUMMARY

In 1982, President Reagan announced that it is U.S. policy to "expand U.S. private-sector investment and involvement in civil space and space related activities." To accomplish this goal, the administration must be prepared to consider alternatives such as providing Government subsidies to encourage commercialization and giving the National Aeronautics and Space Administration (NASA) additional funding and direction to organize itself for assisting in the commercialization process. The latter is particularly important in the areas of educating and communicating to industry what opportunities already exist, and performing research and development necessary for creating a basis on which companies can decide to enter the space business.

The legal and policy issues involved in this developing area are many, and while some have been discussed in the past, the recent surge in proposals from private companies has spurred a new urgency for their consideration and expeditious resolution. Among the issues discussed in this report are:

— The need for NASA to better organize itself for its role in commercial space endeavors in terms of centralizing responsibility, clarifying the types of agreements that are needed/desired with the private sector, and communicating with the private sector;

— The dilemma NASA faces in trying to encourage private sector interest in space endeavors, such as the commercialization of expendable launch vehicles, while protecting its own interests;

— The possible interpretation of the National Aeronautics and Space Act that all private sector space activities must be carried out under NASA's aegis;

— The need for coordination among the various Federal agencies with responsibilities in commercial space ventures, with the potential of designating a lead agency, and between the Federal Government and State and local governments.

— The choices which must be made by the Government between the desire to commercialize space and the potential cost of subsidizing such ventures, and maintaining competitiveness with other countries at the same time;

— The proper role of the Government vis-a-vis the private sector in performing advanced research and development on "commercial" systems;

— The need to regulate private sector space activities, both for safety and for conformance with international treaty obligations;

— The impact of national security requirements on commercialization proposals;

— The need to clarify responsibilities, obligations, funding, contributions, and claims procedures for liability associated with space ventures; and

— The need to reassess patent law to encourage commercialization.

The President's policy is to expand private sector involvement in space, but such activity is not without financial risks to the Government, not only if subsidies are required, but if a commercial venture fails and the Government must buy back into the system. Thus the first important step is to decide if commercialization is worth that risk. If the answer is yes, then the resolution of the other issues can follow.

PART I: POLICY ISSUES INVOLVED IN THE COMMERCIALIZATION OF SPACE

Prepared by Marcia S. Smith, Specialist in Aerospace and Telecommunications Systems, Science Policy Research Division, Congressional Research Service.

INTRODUCTION

Once solely the province of Government-funded research and development, space technology has become an area of increasing involvement by the private sector, not only in terms of R&D, but also in commercial applications.

For many years, NASA has fostered the transfer of space technology to the private sector through technology transfer and utilization programs such as COSMIC (a computerized program for making available to anyone research accomplished at NASA), yielding "spinoff" benefits such as rechargeable pacemakers for the heart. These secondary applications of NASA technology have been extensively detailed in many publications (such as NASA's annual spinoff books).

Recently, however, the private sector has begun showing interest not just in these applications of space-derived technology, but in becoming part of the space business itself. Several companies are actively pursuing the possibility of marketing expendable launch vehicles once NASA phases out their use in favor of the Space Shuttle, while others are involved in cooperative endeavors with NASA to develop processes and hardware for manufacturing materials in space. Companies have also come forward with plans to build space facilities such as a space station in cooperation with NASA. Other private sector activities would involve the takeover of operations of systems which have successfully completed the R&D stage. As with communications satellites, there is now a possibility of the private sector operating land remote sensing and weather satellites, as well as the Space Shuttle once it is fully operational. A summary of space commercialization proposals appears in the appendix.

As this "commercialization" of space takes root, a number of policy issues will have to be addressed. These include: The proper role of the Federal Government versus the private sector in research and development programs, and how to determine when the R&D is completed and a system is operational (and therefore ready for the private sector); how much (if any) of a subsidy should be provided by the Government to assist in commercial opportunities; methods for the Government to encourage space commercialization without creating harmful competition to itself (in providing launch services, for example); how to keep the United States competitive with foreign space ventures; what regulations (if any) are required for commercial activities in space and what agency should be in charge of these regulations; and what the national security implications of commercial activities may be.

4

NASA is currently developing policy guidelines for the commercialization of space and has contracted for two studies (by the National Academy of Public Administration and the Denver Research Institute) in addition to its in-house studies. Policies are expected to be announced during 1983.

This part of the study identifies policy issues which might be involved in certain areas of space commercialization, including remote sensing, expendable launch vehicles, the Space Shuttle, and materials processing in space. Legal issues are discussed in part II of this report.

Communications Satellites—A Case Example

In looking for precedents of where a space activity has successfully been turned into a commercial enterprise, the only example at this time is communications satellites. Only two other fields of space activity have reached what can be considered an "operational" status—weather satellites, and land remote sensing satellites—and both of these are still operated by the Government, although not by NASA.

Considering that the first U.S. communications satellite, Echo, was launched only in 1960, it is remarkable that the potential of this type of endeavor was recognized so quickly and turned into a commercial endeavor. It took less than 2 years from the October 12, 1960 announcement by NASA that it would launch and evaluate private communications satellites to the enactment of the Communications Satellite Act on August 31, 1962. [1]

The intense interest of the private sector in creating a commercial communication satellite system was evidenced by AT&T's application to the Federal Communications Commission (FCC) for authority to do just that on October 21, 1960, barely 2 weeks after the NASA announcement. On January 19, 1961, FCC granted AT&T the authority to establish an experimental transatlantic satellite link. On February 26, 1961, NASA and FCC released a memorandum of understanding in which FCC was identified as having the policymaking role in this area. [2]

FCC issued a notice of inquiry (NOI) on March 29, 1961 to receive views regarding the administrative and regulatory structure of a commercial communications satellite system. Seven proposals were received in response to the NOI, as well as a filing from the Justice Department outlining several antitrust considerations it wanted taken into account: The need for joint ownership by all carriers, for nondiscriminatory access to the facilities, to permit ownership by any interested equipment suppliers, and to assure competitive procurement of equipment.

Following a May report based on the responses to the NOI in which it essentially proposed that satellites be treated similarly to

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[1] Some of the information in this section is condensed from part of a study by the Science Policy Research Division of the Congressional Research Service prepared for the House Committee on Science and Technology entitled "U.S. Civilian Space Programs Volume II—Applications Satellites," which is in press.

[2] Memorandum of Understanding Between FCC and NASA On Respective Civil Communications Activities. Feb. 28, 1961. Published in U.S. Congress. House Committee on Interstate and Foreign Commerce. Communications Satellites. Pt I. 87th Cong. 1st sess. Washington, U.S. Government Printing Office. 1961. pp. 6-7.

undersea cables (as facilities jointly owned by their users), the FCC sponsored an industry conference at which it was agreed to create a committee to formulate the terms, conditions, and operational structure of the system. The committee was composed exclusively of common carriers.

Concerned about the FCC proceedings, President Kennedy wrote to Vice President Johnson on June 15, 1961 and directed him to conduct a study on how, and under what structure, to establish an operational system at "the earliest practical time." [3] Much of the work was performed by the National Aeronautics and Space Council (NASC) in consultation with industry and Government agencies. The NASC report was delivered to the President on July 16, 1961 and recommended private ownership of the U.S. portion of an international communication satellite system, coupled with Government controls to prevent monopolization.

On July 24, 1961, President Kennedy issued a communication satellite policy based on the NASC recommendations, calling for nondiscriminatory access to the system, competitive bidding in the acquisition of equipment, and foreign participation through ownership. [4]

During this time, congressional hearings had begun on the proposal. Held in June, July, and August 1961, they focussed on concerns about potential AT&T monopolization of the system. In October 1961, the FCC-established committee of common carriers issued its report, recommending a nonprofit corporation owned by AT&T and the international record carriers, with the system itself being run by the corporation but each carrier owning its own ground stations.

By the time legislation was introduced in early 1962, arguments over how to approach this issue had coalesced into basically three types of reasoning. One group argued that since the technology had been developed at Government expense, and that one of the goals was to demonstrate U.S. capabilities and good will, then the Government should own and operate the system. Another faction insisted that private companies would be more effective, as evidenced by the fact that, in their view, the United States had the best and cheapest communications system in the world. The third line of reasoning was that although the private sector might be more efficient, there was the danger of monopolization by existing private firms so a new approach was needed—a public corporation.

Three bills were introduced: One at the request of the administration creating a profitmaking, quasi-public corporation with limited ownership interest by the international common carriers, but with real control vested in voting stock controlled by the public; a second by Senator Kerr, chairman of the Aeronautical and Space Sciences Committee, creating a satellite communications corporation owned and operated exclusively by the international carriers; and a third by Senator Kefauver providing for Government ownership of the system.

After extensive congressional hearings (including 9 days by Kefauver's Subcommittee on Antitrust and Monopoly in the Senate

[3] New York Times, June 25, 1961, p. 35.
[4] Department of State Bulletin, Aug. 14, 1961, p. 273.

Judiciary Committee, even though no legislation concerning the issue had been referred there), a filibuster on the Senate floor and an historic cloture motion, the 1962 Communications Satellite Act was passed by the Senate on August 17 and the House on August 27, 1962. The President signed the legislation into law on August 31 (Public Law 87-624).

The 1962 act led to the creation of the Communications Satellite Corporation—Comsat—in 1963. As codified in the act, Comsat would be a private corporation in order to use the profit motive to spur development, would have a broad international charter to enable a global system to evolve, including those services which might not immediately show a profit, and would be organized and operated to preclude domination by a single company through ownership or patent control by having 50 percent of the stock owned by the public, and the other 50 percent by the international carriers.

In essence, Comsat was formed as a publicly owned company with Presidential supervision in the foreign policy area. FCC was directed to ensure effective competition in the purchase of telecommunications goods and services by Comsat, and to regulate the allocation of facilities by Comsat to the satellite system users. In addition, Comsat was required to provide Congress and the President with an annual report of its activities, operations, and accomplishments, and it was to be a "carrier's carrier," meaning that it could not offer services directly to users. The act authorized Comsat to provide goods and services associated with communications services and was initially interpreted as restricting Comsat to that role.

When it passed the International Maritime Satellite Telecommunications Act in 1978, which made Comsat the U.S. signatory to Inmarsat as well as Intelsat, Congress included language directing the FCC to determine whether changes were required in Comsat's structure or operations to ensure that it could fulfill its obligations under the 1962 act. The study, released in 1980, [5] addressed a number of issues, including whether Comsat should remain a carrier's carrier and whether Comsat was prohibited from entering fields other than those related to communications satellites. As noted above, the 1962 act expressly authorizes Comsat to offer communication services, but does not specifically preclude it from entering other areas.

The FCC study concluded that Comsat should be released from its carrier's carrier restriction and that it could provide services directly to end users. Also, the study concluded that Comsat could engage in any activities which are not inconsistent with its statutory mission providing that there is no cross-subsidization between Comsat's regulated services and new competitive services it might begin. An August 1982 FCC memorandum opinion and order issued after comments had been received on the 1980 study reaffirmed this position. [6] This allows Comsat the flexibility to enter other areas, such as the commercialization of remote sensing satellites in which the company has already expressed an interest.

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[5] Final Report and Order (Comsat Study), FCC 80-218, Apr. 22, 1980.

[6] Changes in the Corporate Structure and Operations of the Communications Satellite Corporation. CC Docket No. 80634; FCC 82-372. Released Aug. 13, 1982. Federal Register, vol. 47, no. 181, Sept. 17, 1982. pp. 41116-41135.

The example of how communications satellites became a commercial success is not necessarily directly relevant to today's efforts at space commercialization in other areas, however. First, there was a clear market for the communications services which Comsat was created to provide, something which is not evident today in enterprises such as materials processing in space or remote sensing. Second, a major motive for enacting the legislation was to create an international system, while today's debate concerns U.S. domestic businesses (which might serve the international market, but are not specifically designed for that purpose).

Provisions of the act which may be relevant to the current debate, however, include language such as section 102 which states that it was Congress' intent that "all authorized users shall have nondiscriminatory access to the system," and that Comsat be "organized and operated as to maintain and strengthen competition in the provision of communications services to the public." These principles might well be incorporated into commercial satellite systems for purposes other than communications.

Selected Areas for Study

For the purposes of this report, four areas have been selected for examination: remote sensing satellites, expendable launch vehicles, materials processing in space, and the Space Shuttle. Each is a current topic of discussion in terms of commercial opportunities in space and each presents unique as well as complementary policy issues.

REMOTE SENSING SATELLITES

NASA has developed three types of satellites for remote sensing of the Earth from space: Landsat and Seasat whose names are self-explanatory, and weather satellites which are designated NOAA for the National Oceanic and Atmospheric Administration which operates them along with Landsat. Only one satellite was launched in the Seasat program, and it failed after 100 days in orbit; Government proposals for launching future satellites have been indefinitely postponed.

The land and weather satellites are at the center of a debate on how best to commercialize satellite systems. Although there continues to be controversy over the precise meaning of NASA's charter, there is general agreement that NASA's prime mission (if not its only mission) is research and development (R&D) rather than operations. Thus, when the weather satellites reached an operational status, they were transferred to the Environmental Satellite Services Agency (ESSA) in the Department of Commerce, which later became part of NOAA. NASA retained responsibility for weather satellite R&D and launched several more experimental satellites after control of the operational segment was transferred to Commerce.

When it was determined that the Landsat program could also be declared operational, President Carter decided to give that system to NOAA as well. [7] His plan envisioned eventual transfer to the

[7] Presidential Directive 54, November 1979.

private sector over the course of a decade. Early in 1981, the Reagan administration indicated that it wanted to speed up that transfer timetable. This was the first step in a growing controversy which was greatly broadened when Comsat suggested that weather satellites be included in any transfer arrangement to the private sector.

In response to the Comsat suggestion, President Reagan directed the Cabinet Council on Commerce and Trade (CCCT) to study the feasibility of transferring Landsat and the weather satellites to the private sector. After an initital decision in April 1982 that the weather satellites should remain in the Government, the CCCT was asked to reassess the matter and subsequently recommended full commercialization of land, weather, and ocean satellites. As part of the CCCT reassessment, the Department of Commerce issued a request for information (RFI) from the private sector on whether and how to commercialize Landsat and/or the weather satellites. Only Comsat recommended full commercialization of both the land and weather satellites, and indicated that it was also interested in any future ocean satellites. Other companies indicated interest in parts of the Landsat and weather satellite ground segments, but not in the satellites themselves, and generally concluded that the full transfer of Landsat should take place over a period of time. One company, American Science and Technology (AS&T), expressed interest in the Landsat command and control segment, but expressed a preference for launching its own, privately developed land remote sensing satellites. AS&T sees a need for specialized remote sensing services (such as for oil companies searching for telltale geological formations which indicate oil deposits) and it plans to launch three small satellites using a privately developed launch vehicle called Conestoga. Space Services, Inc., developer of the Conestoga, is a majority shareholder in AS&T.

The major problem in commercializing Landsat is the lack of an identifiable market for the data products which would assure a company of making a profit. Comsat's solution to this problem was the suggestion of including weather satellites in the deal, since the Government itself would buy 95 percent of the data. The Comsat response to the RFI included possible terms that it would make in an offer for the land and weather satellites: Payment of $250 to $350 million for existing satellites and ground equipment, plus a guaranteed Government purchase of approximately $300 million of data every year for 15 years. The latter condition could be considered a Government subsidy, and it has also been pointed out that Comsat could get a significant tax break by investing in the new system.

The problems involved in the transfer of remote sensing satellites to the private sector have been extensively discussed in many sets of congressional hearings since 1973 (the year after the first Landsat was launched) and reports.[8] They need not be restated here, since the main purpose of including remote sensing in this discussion is to assess the current problem with commercializing

[8] See for example: Landsat—Earth Resources Satellite System, CRS Issue Brief 82066, and Commercialization of Landsat and the Weather Satellites, CRS Issue Brief 83072.

satellites in comparison with the case example of communications satellites discussed previously.

First, one clear difference is that communications satellites had a developed market for their services and Landsat does not. This has led to the question of how much, if any, subsidy should be provided in order to increase the commercial attractiveness of the system. Also, without a clear profitmaking market, there is always the possibility that the private entity would terminate its involvement if the program lost money, raising the question of how much it would cost the Government to buy back into the system.

The issue of commercializing Landsat has been complicated by Comsat's suggestion to include the weather satellites. Although it has its own meteorological satellites, the Department of Defense (DOD) uses the NOAA weather satellites on occasion, thus raising national security issues if the weather satellites are operated by the private sector. A transfer of Landsat to the private sector also presents national security issues, but these might have been dealt with more readily without added concerns about weather satellites.

The concern of the public was raised by the announcement to transfer weather satellites to the private sector, both in terms of whether they would still be able to see satellite maps on their local news programs, and in terms of services which are provided by the Government based on the weather data, such as frost forecasts. Unfortunately, at about the same time as the Government announced the transfer of the weather satellites, other changes in the Weather Service were made known, including the fact that certain services (such as frost forecasting) would subsequently have to be purchased from private weather services rather than provided free by the Government, and that some Weather Bureau stations would be closed. Although these actions are unrelated to the issue of transferring the satellites to the private sector, they were all linked together in the press and the public mind.

A third complication arose when it was revealed that the Department of Commerce official in charge of studying the satellite transfer issue had been approached by Comsat concerning future job opportunities, thus leading to at least the appearance of impropriety. [9]

Thus the issue of transferring Landsat to the private sector has become tangled with many other issues which will ultimately have to be sorted out by Congress before action takes place. In fact, language requiring congressional consultations on the transfer plan was placed in several pieces of legislation, including an emergency jobs bill and the fiscal year 1984 NASA authorization bill.

EXPENDABLE LAUNCH VEHICLES

Another area in which policy is expected soon is the commercialization of expendable launch vehicles (ELV's). These rockets are the type which have been used since the beginning of the space program, and include all launch vehicles other than the Space Shuttle. In the United States, four ELV's are in use: Delta, Atlas-Centaur, Titan, and Scout. The last is a very small vehicle capable

[9] Washington Post, April 15, 1983, pp. A1, 12.

of placing only small payloads into orbit and is not being proposed for commercial operation.

In the case of ELV's, one issue involves Government subsidies, specifically whether the companies that are commercializing the vehicles should be required to pay back the Government for sunk costs in R&D. These have been roughly estimated as $91 million for Delta, $600 million for Atlas-Centaur, [10] and $1 billion for Titan 34D. [11] One argument is that these costs should be paid back to the Government since the companies will now be making profits on Government-developed hardware, while the counterargument is that neither the Space Shuttle nor the European Space Agency's Ariane launch vehicle, with which these ELV's would compete for traffic, are expected to recover sunk costs in their pricing schemes, so the commerializers of the ELV's should also not be expected to recover those costs.

The companies that are proposing commercialization of existing ELV's or constructing new ones are identified in the appendix. Unless they plan to build their own launch facilities (only two, ARC Technologies and Space Services, have indicated such plans), they will have to make arrangements for lease or purchase of Government facilities. In the case of the existing ELV's, all the pads are owned by the Air Force, although NASA currently leases the launch pads for Delta and Atlas-Centaur from the Air Force and a private company could sublease through NASA. Also, range safety services must be acquired to ensure, for example, that if the launch vehicle deviates from course it can be safely destroyed. These services are currently provided by the Air Force.

Other areas in which private companies launching ELV's would have to coordinate with the Government include complying with treaties such as the 1967 Outer Space Treaty which states that governments are responsible for all launches from their territory, and the 1972 Convention on International Liability for Damage Caused by Space Objects, which makes governments responsible for compensation for damage resulting from satellite launches (see part II). Launches would also have to be approved by the Federal Aviation Administration (FAA) for clearing the airspace during a launch, and frequencies for transmitting commands to and/or recieving data back from launch vehicles must be assigned by the Federal Communications Commission (FCC).

Only one private launch has successfully taken place to date—the 1982 test launch of Space Services' Conestoga rocket. The procedures required to gain approval for that launch were time consuming, and have led to the introduction of legislation in Congress to ease the way for companies wishing to pursue such activities. The bill introduced in the House by Congressman Dan Akaka (H.R. 1011) would designate the Department of Commerce as lead agency, while the Senate bill introduced by Senator Ernest Hollings (S. 560) would give that role to the FAA.

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[10] These costs were estimated by NASA and do not include the development of the Thor booster on which the Delta design is based, nor the Atlas vehicle from which the Atlas-Centaur combination developed. Telephone conversation, April 1983.

[11] DOD estimate. Telephone conversation, April 1983.

Suggestions have also been made that either the State Department or NASA serve that role—State Department because it is ultimately responsible for adherence to the treaties governing space activities, NASA because of its expertise. The problem with assigning responsibility to NASA is potential conflict of interest. NASA is in a dilemma with regard to the commercialization of ELV's because although it wants to promote space activities in the United States, it has developed the Space Shuttle, with which commercial ELV's would compete. The national policy is that once the Shuttle is fully operational, all Government utilization of ELV's will cease. It is difficult to establish a policy which on the one hand promotes broad opportunities for commercial space endeavors while not creating competition for NASA's own system.

A high volume of uses for the Shuttle must be found in order to ensure that it will meet its expected economies. Already NASA has had to change its pricing strategy just to maintain a competitive posture with regard to the Ariane launch vehicle developed by the European Space Agency (ESA). Instead of recouping full costs of the Shuttle, NASA will now charge only enough to recover operating expenses. The impact of a fleet of privately operated ELV's, while providing a boom for customers, could spell doom for the Shuttle.

The Government's policy to phase out ELV's is what led to the proposals to commercialize the ELV's, because the private sector senses that there will be a market both for the Shuttle and the existing type of launch services. An important factor in this argument is whether NASA will procure a fifth Space Shuttle orbiter, for that will partially determine how often the Shuttle will fly, and therefore how many payloads it can take into space. Without the fifth orbiter, the Shuttle may be overbooked and customers might be willing to switch to an ELV. Another factor is whether the Shuttle system will meet its expected launch rate of 24 launches per year with 4 orbiters, which would also affect the number of customers looking for alternative launch arrangements. Some might want to double book on an ELV as insurance against a potential catastrophic failure of one or more orbiters.

There are obstacles to commercial ELV operators, however. For example, the United States is no longer the only country offering space launch services. ESA is aggressively marketing its Ariane launch vehicle and planning improvements to make it even more versatile and capable. In addition, there are signs that the Soviet Union may start offering launches on a commercial basis.

Thus there is competition for ELV operators not only from the Shuttle, but from other countries. The Office of Management and Budget (OMB) denied NASA's request for funding to procure a fifth orbiter in fiscal year 1984 because it did not see a need for another orbiter to meet expected traffic demands, so it is unclear as to whether a market really exists for all these different types of launch services.

Another potential obstacle is national security considerations both in terms of what types of satellites can be launched without adversely impacting the interests of the United States, and possible restrictions on the export of launch vehicles or launch vehicle technology.

It should also be noted that two companies have financed or are financing the development of upper stages for use either with the Shuttle or with ELV's. McDonnell Douglas developed the payload assist module (PAM) for use either with its Delta or with the Shuttle at its own expense, and markets the stage commercially. Recently, NASA signed a cooperative agreement with Orbital Systems Corp. (OSC) to develop an upper stage with an intermediate range of capability called the transfer orbit stage (TOS). OSC will privately fund development of TOS, although NASA will provide technical oversight at no charge. Under the cooperative agreement, NASA has also promised not to develop a similar vehicle of its own, although this does not preclude development by another company. NASA had been planning to develop such a stage itself until OSC offered to fund the project. If OSC drops out for any reason, NASA has indicated that it will step in. [12]

MATERIALS PROCESSING IN SPACE

The single area in which most discussion is heard concerning commercial space opportunities, or the "industrialization" of space, is in materials processing in space (MPS). Although NASA has very limited experience with MPS (only about 8 hours worth of experiments were conducted during the Apollo and Skylab programs) there is hope that there may be major industrial opportunities in this area.

NASA has two types of agreements which it offers in terms of MPS experiments; there is no exchange of funds in either case. One is the joint endeavor agreement in which NASA and the sponsoring organization share data from an experiment in return for a free Shuttle launch. There are only two existing joint endeavor agreements on MPS. One is with McDonnell Douglas working with Johnson and Johnson on electrophoresis experiments; this experiment has flown on two Shuttle missions already. The second is with Microgravity Research Associates to develop a process for the production of semiconductor materials. Another joint endeavor agreement, with GTI Inc. for the development of a furnace for use in MPS, was terminated after 1 year because GTI saw no immediate market for the device.

The other type of agreement is a technical exchange agreement in which companies are allowed to use existing NASA facilities for MPS experiments in return for data from the experiments. These facilities include, for example, sounding rockets, drop-tubes, and aircraft which fly in hyperbolic curves to create a few seconds of zero-g. NASA currently has technical agreements with John Deere, Honeywell, Dupont, and Inco. In addition to the activities done in cooperation with NASA, some companies are pursuing MPS research on their own. These companies are identified in the appendix.

The major obstacles in the path of MPS include lack of knowledge about the products or processes that might be developed in space factories because so little experimental work has been done, and the lack of orbital facilities for companies who want to per-

[12] Telephone conversation with a NASA representative, April 1983.

form MPS experiments. These issues underscore the importance of the debate over the proper role of the Government versus the private sector in such endeavors. There is a feeling among the private sector that NASA should be provided with more funding to perform basic research needed to identify the directions in which a company could proceed in order to develop a profitmaking enterprise, but NASA's space science and applications budget has been sharply constrained in the past few years. Also, there is the problem of who should develop the hardware for MPS. For example, one company representative explained that GTI Inc.'s decision to terminate its agreement with NASA for development of a furnace for MPS has left them in a quandry because there is no furnace available at this time suitable for their experiments. They do not want to spend money to develop a furnace themselves, so the future of their MPS program is in doubt. The representative stated that it did not matter to his company whether it leased facilities from NASA or from a private company such as GTI, just so it did not have to be responsible for providing such hardware. [13] Without the GTI agreement, however, which was terminated for lack of a defined market, the question remains as to who will develop the hardware.

Other areas in which concerns have been expressed include patent law and protection of proprietary information. These issues are discussed in part II of this report.

SPACE SHUTTLE

Operation of the Space Shuttle

Who should operate the Space Shuttle once it is no longer in an R&D phase has been a question debated for many years—without resolution. Communications, weather, and remote sensing satellites have all been transferred out of NASA once they were operational, so the question has arisen as to whether the Shuttle, too, should be transferred to another Government agency, the private sector, or a quasi-governmental organization.

A discussion of the options available for commercial operation of the Shuttle is beyond the scope of this report. Consequently, only the major policy issues will be identified. The first concerns military payloads. Assuming that DOD would not want to be dependent upon a commercial company for launch services, one option is to have DOD operate the entire Shuttle fleet. A second option would be to give DOD its own fleet of Shuttles while having a separate fleet for commercial and civil space flights (called "blue" and "white" fleets respectively). Of course, DOD might be persuaded to buy launches from a commercial company as long as certain safeguards and contingencies were provided for.

If NASA were to retain operational responsibility, the issue arises as to whether its budget would be adequately augmented to provide for whatever changes the agency would have to make organizationally and in hiring personnel. The NASA budget has been constrained for many years already because of the investment in the Space Shuttle, and concern might arise as to the health of

[13] Telephone conversation with representative of John Deere, Co., April 1983.

other NASA activities if large sums continued to be required for the STS system.

It is commonly argued, however, that the Government simply is not good at marketing what it develops and, once operational, a system should be handed over to the private sector. If this is done, the issue of Government subsidies will arise, both in terms of whether or not a private company would be required to pay back the Government for some or all of the sunk costs in the Shuttle, and in terms of whether the Government would be willing to subsidize a company in order to ensure that it could price Shuttle launches competitively with other launch vehicle options, particularly foreign ones. On the other side of the question is what, if any, restrictions the Government might impose on pricing. For example, NASA currently does not permit McDonnell Douglas to charge more than 30 percent of the internal rate of return (IRR) for the payload assist module. [14] Similar strictures might be imposed on Shuttle pricing as well, possibly making such an enterprise less attractive to the private sector.

As in the case of remote sensing satellites, there is the issue of how much it might cost the Government to buy back into the Shuttle system if the private entity decided to terminate its involvement because it was not profitable.

Another issue is who would perform R&D associated with improving the Shuttle system. Proposals have already been made to develop an unmanned version of the Shuttle (called SRB–X) using the solid rocket boosters for a heavy lift capability, and other improvements are likely to be identified as experience with the vehicle grows. If the private sector takes over operation of the Shuttle, would it be responsible for improvements, or would the Government continue to fund such activity as it has with communications satellites?

Shuttle-related hardware opportunities

The Shuttle also presents other commercial opportunities. The Shuttle is often described as a space truck, hauling cargo back and forth into space. Long-term facilities, either unmanned platforms or manned space stations, may be built by the Government or by the private sector to augment the Shuttle. It is generally accepted that the private sector cannot afford a massive R&D investment such as that needed for a manned space station, although one company, Space Industries, is discussing with NASA the possibility of a joint development. There also has been one proposal for an unmanned platform. Called Leasecraft, the device would provide power and communications subsystems, as well as an orbital maneuvering capability if refueled in space, for factories and perhaps observatories. The proposal is being made by Fairchild Industries and is based on the multimission modular spacecraft it developed for NASA and which has been used for the Solar Maximum Mission and Landsat 4. In addition, two companies have shown interest in designing facilities for use in the Shuttle cargo bay (see appendix).

[14] Meeting with NASA representative, April 1983.

Other opportunities may also present themselves in areas such as providing in-orbit power supplies for the Shuttle to allow it to stay in orbit for extended periods of time, development of a reusable Space Tug, development of a teleoperator retrieval system, and so forth. Although these are areas in which industry expects (or at least hopes) that NASA will take the lead, if it does not, the private sector may wish to proceed itself.

Private purchase of a fifth Shuttle orbiter

A different kind of proposal related to the Space Shuttle is one by SpaceTran Inc. to purchase a fifth Shuttle orbiter for NASA in exchange for marketing rights to commercial and foreign payloads. The first informal proposal was submitted to NASA in the spring of 1982 and reportedly asked for exclusive marketing rights to all Shuttle commercial and foreign payloads. Following discussions with NASA, this apparently has been modified, but the details have not been released.

In early 1983, Federal Express agreed to purchase 20 percent of SpaceTran and the company is now reassessing its plans. Although SpaceTran was expected to resubmit a plan to NASA on March 1, 1983, none had been submitted at the time this report was prepared. (SpaceTran is also working with Martin Marietta on the commercialization of the Titan launch vehicle.)

The SpaceTran offer not only demonstrates interest from the private sector in the Shuttle system, but would save NASA approximately $1 billion if approved. Although OMB rejected NASA's request to purchase a fifth orbiter because it did not see a market for it in the projected Shuttle flight manifest over the next decade, apparently SpaceTran is confident that such a market exists.

Payload and Space Shuttle processing

Also associated with the Space Shuttle are plans for building processing facilities at Kennedy Space Center. At the present time, NASA processes the payloads for both the Shuttle and ELV's, but the NASA facility is overloaded. Astrotech International is now building a complementary facility near KSC and has arrangements with NASA to ensure that payloads processed there will meet NASA standards, although these arrangements are only in an exchange of letters, not through a formal mechanism such as a cooperative agreement or memorandum of understanding. [15] Hughes Aircraft also is actively considering construction of a payload processing facility near KSC in conjunction with a facility for satellite assembly. [16]

NASA is also getting close to choosing a company for its Shuttle processing contract (SPC) at KSC. This will involve onsite processing (preparation for launch) of the Shuttle itself rather than its payloads, and is expected to be a multimillion dollar contract over several years. The SPC will cover Shuttle processing both at KSC and at Vandenberg Air Force Base, which will be the west coast launch site for the Shuttle beginning in 1985. Currently, Shuttle processing is performed by several contractors that supply the

[15] Telephone conversation with Astrotech International representative, April 1983.
[16] Telephone conversation with Hughes representative, May 1983.

flight hardware (Rockwell International, Martin Marietta, and United Space Boosters, Inc.). The SPC would consolidate this activity. [17] This is not directly related to the issue of whether and how to commercialize the Shuttle, but is seen as a step in making the Shuttle ready for its operational era, whatever arrangements are ultimately chosen.

Policy Issues

Although each of the areas discussed above presents unique policy questions, there are also broad issues which affect more than one area. Some of these have been mentioned already, but this section will summarize them. Legal issues are discussed in part II of this report.

PROPER ROLE OF THE GOVERNMENT IN SPACE COMMERCIALIZATION

Subsidies/financing mechanisms

There are several different ways in which the Government might wish (or be expected) to subsidize commercial space ventures: Through guaranteeing purchase of certain amounts of data or numbers of vehicles such as upper stages; through direct subsidies to make a commercial venture competitive with foreign systems; through not requiring payback of sunk Government costs in a system; or through tax incentives.

In an era of tight budgets, Government subsidies are viewed with increasing concern, but they may be necessary if it is decided that transferring these systems to the private sector and/or maintaining U.S. competitiveness with foreign systems such as Ariane have an overriding importance. Many of the programs which are being considered as commercial prospects do not have defined markets, making them less attractive for private investment. Without guarantees that, at least, no money will be lost, the private sector simply may not be willing to get into the space business.

One alternative that has been discussed is the potential of establishing a Space Bank or Space Industrialization Corporation to provide venture capital/financing for commercial space endeavors. These proposals have been viewed as premature for the past several years, but might bear reexamination at this time. They might require Government funding initially, but are meant to be self-supporting eventually.

Related to this issue is how much it might cost the Government to buy back into a system that had been transferred to the private sector, but which was not profitable. Without subsidies to ensure financial success for a company, the Government might end up, for example, without remote sensing data or access to appropriate upper stages. In some cases, the only alternatives might be to purchase the data or hardware from other countries, or to reinstate Government ownership of the system. Thus, the advantages of commercialization must be weighed against the potential failure of a commercial endeavor and resulting costs to the Government.

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[17] Proposals Requested for Shuttle Processing Contract. NASA Press Release 83-3. Jan. 20, 1983.

Federal role in research and development

The issue of what role the Government should play in research and development vis-a-vis the private sector has been debated for many years. In the space business, this has been particularly visible in the case of advanced communications satellites R&D. NASA performed such R&D long after commercial communications satellites were available, but in 1973 the NASA program was terminated on the basis that the private sector should bear responsibility for advanced R&D. The private sector did not pick up the challenge, because they said it was too expensive, and NASA reentered the field in 1979. During that time, however, foreign countries such as France and Japan forged ahead in the technology.

With increasing space commercialization, the issue of who should perform both basic and advanced R&D will take on greater import. If systems such as the Space Shuttle, remote sensing satellites, and MPS are to continue to evolve, the Government may have to provide funding if the private sector is unwilling or unable to fund the R&D.

In the case of MPS, for example, the basic R&D must be done before a company can identify profitable directions to pursue. NASA has developed mechanisms such as joint endeavor agreements to encourage private sector participation in MPS, but no funding is provided and the experiments can prove prohibitively expensive for an interested company. It may be necessary to increase support for initial R&D funded by the Government if commercial activity is deemed important. A related issue is development of hardware needed for experimentation. Companies that might be willing to pay for an MPS experiment might not be willing or able to develop their own facilities, such as furnaces, which are not now available from NASA or private companies. A joint endeavor agreement between NASA and GTI Inc. for development of a furnace was terminated for lack of an identifiable market. Who then will develop such devices?

If the Government performs the R&D, another aspect of the issue is the relationship between the Government and the private sector in establishing what research should be done. NASA has been criticized in the past for performing R&D without adequate user input; steps might be taken to ensure maximum user involvement from the beginning.

Maintaining U.S. competitiveness with other countries

Both of the above issues are related to the question of how the United States can remain technologically competitive with other countries. This has been the subject of growing concern in the past few years, and one of the areas in which the United States has lost or is losing its lead is communications satellites.

The close relationship between Government and industry in foreign countries, unlike the separation between the two in the United States, is often viewed as creating unfair competition for U.S. goods and services. In the case of Ariane, for example, ESA has made it clear that it will subsidize that launch vehicle to whatever extent is necessary to make it competitive with the Space Shuttle. NASA is much more limited in what it can do to subsidize

the Space Shuttle without specific direction from the administration and Congress.

The 1958 National Aeronautics and Space Act states that the United States will remain a leader in world space activites, a theme echoed by recent administrations. If this truly is a major policy goal, then subsidies and Government sponsored R&D may be the sine qua non for maintaining that leadership.

Government fostering competition with itself

Apart from the question of U.S. competition with other countries is the question of how the Government can support commercial space endeavors without creating adverse competition for its own systems. A case in point is the commercialization of ELV's at the same time NASA is trying to prove the economies of the Space Shuttle system. This obviously creates quite a dilemma for NASA, which on the one hand is trying to encourage private sector interest in space, but on the other wants at least to break even on the Shuttle system. Statements from NASA officials show optimism that the Shuttle will prove itself in terms of economics as well as reliability, and the commercial ELV's will not seriously impact Shuttle business. Whether this is true or not remains to be seen. The question is whether NASA should actively encourage ELV commercialization, or simply endure it.

A related issue is what price controls NASA can impose on private sector operators and whether it could thereby unfairly affect the commercial attractiveness of ELV's. For example, NASA currently does not allow McDonnell Douglas to charge more than 30 percent of the internal rate of return on the PAM upper stages, and similar constraints might be placed on other systems.

NASA organization

An important aspect of the commercialization process is how NASA itself is organized to handle commercial proposals and how it communicates commercial opportunities to the private sector.

As described in the appendix, NASA has three different mechanisms for encouraging commercial space endeavors, but it is difficult to determine the differences between the three, what types of activities require what (if any) types of agreements in addition to those mechanisms (such as memoranda of understanding), and the status of various undertakings. Thus, it is difficult to determine the effectiveness of these mechanisms for promoting commercialization. Attention might be paid to the centralization of responsibility for these activities.

Another problem is how NASA educates the private sector about potential opportunities. For example, a criticism has been raised that NASA personnel involved in MPS research rarely give papers at technical meetings attended by scientists from the private sector who might benefit from that knowledge. Private meetings between specific companies and NASA representatives are hindered by limits on NASA's travel budget and restrictions on what the private sector is allowed to pay for without creating the appearance of impropriety between Government and industry. At the same time, NASA's budget for technology transfer and utilization activities is being cut. Mechanisms for better educating the private sector must

be developed if a commitment to commercialization of space is made.

Fifth orbiter/advanced in-orbit space facilities

Another factor which may impact on the commercialization of space is the availability of an adequate space transportation system and in-orbit space facilities, such as space stations or platforms, to support commercial activities.

One part of this concerns the debate over whether or not to procure a fifth orbiter. Although NASA and OMB agree that there is currently no requirement for a fifth orbiter, NASA is more optimistic that such a need will develop once the full potential of the space environment is realized. The question is whether the need will arise if there is no commitment to a fifth orbiter. A similar question arises with respect to space facilities, manned or unmanned, which would be needed for a full scale commercial enterprise.

Without commitments to these sorts of activities, a private company might not be willing to make the initial investment in research which would lead to future commercial activities, since there would be no guarantee that it could make use of whatever knowledge it gained.

Regulatory Issues

Regulatory issues are likely to arise as various space activities become more commercialized. At the present time, ELV's can serve as an example of some of the considerations that must be taken into account.

Types of satellites to be launched

Restrictions may have to be placed on the types of satellites that can be launched by the private sector. It is assumed that space systems with aggressive missions, such as antisatellite devices, would not be launched by a private company. But what if another country wanted to launch a military reconnaissance satellite? Or a navigation satellite intended primarily for civil use, but which could be diverted to military uses in times of crisis? Would such a launch be prohibited? Would it only be prohibited if it took place from U.S. soil, or could a company sell its launch vehicle to another country for launch from another site?

Similarly, how will restrictions on the resolution of remote sensing satellites be enforced for private operators (currently, the Government does not permit remote sensing satellites to have better than 10 meter resolution)? Will these restrictions apply to satellites constructed by other countries but launched by U.S. firms?

Regulations concerning export of launch vehicles/technology

Will private firms be allowed to export launch vehicles for launch from another country's launch site? This is important not only in terms of what type of satellite could be launched as noted above, but what the launch vehicle itself might be used for. Most launch vehicles (including Delta, Atlas, and Titan) were developed from military IRBM or ICBM technology. Assurances might have to be gained from the receiving country that they would not be

placed back into military service, as was done when Japan was allowed to manufacture Delta launch vehicles under license from McDonnell Douglas. With the growing awareness of the "giveaway" of U.S. technology to other countries, concerns might also be raised about how the launch vehicle technology might be used.

Lead agency identification

There are many other regulations concerning ELV's that will have to be dealt with, including assurances that launches will not violate treaties to which the U.S. is a signatory, the use of radio frequencies, clearing airspace around the launch site, and so forth. These have already been widely discussed in congressional hearings and the trade press. Legislation has been introduced in the House and Senate concerning designation of a lead agency as the point of contact for private firms wishing to engage in commercial ELV activity. Ostensibly this would ease the way for the private sector, making such endeavors more attractive, and might also serve the Government's interest in terms of coordinating procedures.

If a lead agency is designated, the question arises of which agency it should be. Four agencies have been mentioned: The Department of Commerce, the Department of Transportation (specifically the FAA), the Department of State, and NASA itself. The House bill (H.R. 1011) recommends the Department of Commerce since it is sensitive to the needs of the private sector, while the Senate bill (S. 560) recommends FAA since it has experience in the related area of aeronautics. Department of State has been suggested (so far informally) perhaps because it is ultimately in charge of adherence to treaty obligations, and NASA has been mentioned because of its obvious expertise in the space launch business, although it might have a conflict of interest since commercial ELV's would be competing with its Space Shuttle. One suggestion has been to name NASA as an interim contact point, while deferring a decision on what agency should serve as the lead.

Role of State and local governments

The above issues discuss possible regulations by the Federal Government, but State and local governments may also have a role to play, especially if new launch sites are established within their borders. For example, Space Services Inc. launched the Conestoga rocket from Texas and there has been some discussion of establishing a launch site in Hawaii. What role the State and local governments should play will need to be determined in the near future, particularly with regard to coordination with the Federal Government.

Monopolies

A major issue during consideration of the 1962 Communications Satellite Act was how to prevent a monopoly from developing in the area of providing satellite communications services. Similar concerns will likely develop in the commercialization of other space technologies, and have, in fact, already been raised in connection with the land and weather satellites, and ELV's.

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National Security

National security issues are also likely to impact on commercialization decisions such as who should operate the Space Shuttle, access to commercial ELV's by DOD in times of crisis, access to privately owned launch sites in times of crisis, resolution limits on remote sensing satellites, use of commercial ELV's by foreign governments, and technology transfer in general (including, for example, building ground stations in foreign countries for receiving data from U.S. commercial satellites such as those proposed by American Science and Technology for remote sensing). One question is what agency should be responsible for ensuring that national security issues are resolved. DOD would seem a natural choice, but also might be viewed by the private sector as placing too many constraints on operations, so a more neutral agency, perhaps one of those being considered for lead agency responsibility for ELV's, might be designated instead.

Conclusion

The field of space commercialization is expanding rapidly. Many companies are showing interest in commercial space activities ranging from expendable launch vehicles to remote sensing satellites to materials processing in space.

President Reagan's 1982 space policy states that commercial space endeavors are to be encouraged as long as they are consistent with national security, but many policy issues remain to be resolved. The expeditious resolution to these many issues is needed if commercialization is to proceed full pace, but their complexity makes such quick action unlikely. In the meantime, consideration might be given to providing NASA with direction and funding required to centralize its activities related to commercialization and to perform necessary research and development to provide a sound basis upon which the private sector can make decisions about investing in space. Additional NASA resources may be needed for educational functions to increase the awareness of private companies as to what opportunities already exist.

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PART II: THE COMMERCIALIZATION OF SPACE TECHNOLOGIES: SOME PRESENT AND FUTURE LEGAL ISSUES

Prepared by Daniel Hill Zafren, Specialist in American Public Law, American Law Division, Congressional Research Service.

INTRODUCTION

An attempt is made here to discuss and analyze some of the diverse and complex aspects of legal control that are or may deserve consideration in the commercialization of space technologies, that is, in the transition of Government owned and operated civilian space activities to strictly private ownership and operation, or civilian space activities originating through private initiative. By necessity, this overview must in large part be general in nature. A more particular assessment would have to be premised on the specific facts and circumstances surrounding any such actual transfers or ventures. Such items as the type and scope of the activity, the location of its inception and operation, and the nature of the entities participating, may be of special relevance. Positions and viewpoints of participants, existing and potential competitors, consumers and users, governmental agencies, international organizations, or other nations, might be germane to legal considerations or determinations.

Thus, the present and future legal issues raised here require an international law as well as a domestic regulatory diagnosis. This entails a narrow circumspection based on the particular space activity involved, and a broader evaluation covering regulations or controls over business activity and technological development in general.

INTERNATIONAL LEGAL RESPONSIBILITY AND LIABILITY

No matter what the form and content of the arrangement for the United States to domestically shift the ownership and control of its space activities, any such unilateral act would appear to be without international legal effect. Thus, it would be the United States itself that would be held accountable under treaty law and customary international law for the obligations and responsibilities concerning such activities or even "pure" private activities. Internationally, such a transfer would appear to place the United States in a theoretical dichotomy. It will have given certain direct rights and privileges it has enjoyed under international law to the private commercial interests of its citizenry while still being primarily liable for a wide array of adverse effects that might emanate from the exercise of those rights. Since Article 6, Cl. 2 of the Constitution of the United States makes treaties the supreme law of the United States, U.S. citizens would be bound as a matter of domestic law by the self-executing provisions of space treaties in exercising actions or

activities covered thereby, and the authority settled upon by the United States governing any transfer might expressly provide for actual fulfillment of international requirements. However, such would not displace the United States as an actual obligor under international law.

SPACE LAW TREATIES

Four major multilateral treaties, drafted and signed under United Nations auspices, comprise the corpus of space law today. The so-called Outer Space Treaty [1] is the most fundamental agreement, and the one upon which the later treaties were elaborated or expanded upon. Probably the most germane provision for the purposes of the discussion here is that portion of Article VI which reads:

ARTICLE VI

> States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the moon and other celestial bodies, whether such activities are carried on by governmental agencies or by nongovernmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of nongovernmental entities in outer space, including the moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty.

Importantly, this provision makes no distinction between activities carried out by the State itself or by its private commercial enterprises. Thus, it would be applicable to all space activities, such as telecommunication satellite activities. "Therefore, as opposed to the traditional rule in telecommunications, States are responsible for outer space activities carried out by any of their private nationals and firms, even if the State does not exercise any direct or indirect control over such activities. Indeed, failure to undertake this responsibility would constitute a breach of the principle of control and supervision over non-governmental entities as stated in the second sentence. . ." [2]

Some other basic obligations and responsibilities can be found in the Outer Space Treaty. The premise for international liability for damage is set forth in Article VII:

ARTICLE VII

> Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is in-

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[1] Treaty of Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, January 27, 1967[1967], 18 U.S.T. 2410, T.I.A.S. 6347

[2] N.M. Matte, *Aerospace Law-Telecommunications Satellites* (1982), at 81.

ternationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the moon and other celestial bodies.

Retention of jurisdiction and control over objects in outer space is covered by Article VIII:

ARTICLE VIII

A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body. Ownership of objects launched into outer space, including objects landed or constructed on a celestial body, and of their component parts, is not affected by their presence in outer space or on a celestial body or by their return to the Earth. Such objects or component parts found beyond the limits of the State Party to the Treaty on whose registry they are carried shall be returned to that State Party, which shall, upon request, furnish identifying data prior to their return.

Some of the other obligations contained in this Treaty are: carrying on activities in accordance with international law (Article III); avoidance of contamination; avoidance of adverse changes in the environment of the Earth from the introduction of extraterrestrial matter; and international consultations in certain instances before proceeding with activities or experiments. There is, of course, room for great variation in interpretation of these or other prescriptions, as well as to whom, and to what extent they would actually apply. [3]

The so-called Astronaut Assistance and Return Agreement [4] elaborates on the general provisions of the Outer Space Treaty dealing with assistance to be given to astronauts, and provides for such matters as notification of accidents, and the rescue and return of spacecraft personnel and space objects. "Launching authority" as used in this treaty refers to the State "responsible" for launching (Article VI). A number of potential legal problems that might need addressing can be envisioned. For example, if there is a launching of a space object by private U.S. industry that falls within the territory of another Party to the Treaty, that Party's responsibility is to notify the launching State (the United States), and if requested by it and with its assistance to recover the object or its component parts and at the launching State's expense. What kind of obligation, including items such as timing, form and content, as regards sending or receiving such notifications would or should

[3] Added uncertainity can be found concerning the pending so-called Moon Treaty. See. e.g., Congressional Research Service, Senate Committee on Commerce, Science, and Transportation, 96th Cong., 2d Sess. *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, Part 4 (Committee Print 1980).

[4] Agreement on the Rescue of Astronauts, the Return of Astronauts, and the Return of Objects Launched into Outer Space, April 22, 1968 [1969], 19 U.S.T. 7570, T.I.A.S. No. 6599.

exist between the U.S. Government and the involved private industry? To what extent would or should each participate in the decision to request a return, the kind and participation of assistance, and the bearing of expenses? Additional legal complexities can be speculated on if the object lands in a nation not Party to the Treaty.

The so-called Outer Space Liability Convention [5] establishes the rule of absolute liability for a launching State for losses suffered by persons (other than its nationals) and property from reentering space objects and their components. Even though this Treaty has been the subject of criticism as being legally inadequate to govern many liability questions concerning space activities, [6] since a launching State is defined therein as including a State from whose territory or facility a space object is launched, the United States has a potential absolute and unlimited liability for deaths, injury or damage caused by space objects (or their parts) launched by its nationals from within its territory or from a facility of the United States (even if on the high seas). A resolution of how such liability should be affixed in such instances, including the manner in which claims are to be handled, would appear to be a major prerequisite for any domestic scheme to promote private space activities or any arrangement of transferring present Government operations or activities in space to the private sector.

The so-called Registration Convention, [7] requires a launching State (again defined as including a State from whose territory or facility a space object is launched) to enter each launching in an appropriate registry with certain information to be furnished to the Secretary General of the United Nations. The division/responsibility concerning such functions would also seem to be a matter for domestic operational agreement.

SOME OTHER TREATIES

A number of additional multilateral agreements to which the United States is a Party may be germane with respect to any particular kind of privately run activity, or possibly problematical with the U.S. (or its representative) membership in certain international organizations, or possibly contrary to or inconsistent with the rules set up thereunder. For example, Intelsat, the International Telecommunications Satellite [8] Organization, is an organization established for the purpose of continuing and carrying forward on a definitive basis, the design, development, construction, establishment, operation and maintenance of the space segment of the global commercial telecommunications satellite system. Recently, an application filed by a private corporation with the FCC seeking permission to build and launch two satellites over the Atlantic to

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[5] Convention on International Liability for Damage Caused by Space Objects, March 29, 1972 [1973], 24 U.S.T. 2389, T.I.A.S. No. 7762.

[6] See, e.g., M.D. Forkosch, *Outer Space and Legal Liability* (1982). For a favorable analysis, see C.Q. Christol, *The Modern International Law of Outer Space* (1982), at 59-104.

[7] Convention on the Registration of Objects Launched into Outer Space, January 14, 1975 [1976], 28 U.S.T. 695, T.I.A.S. No. 8480

[8] Agreement Relating to the International Telecommunications Satellite Organization (Intelsat), August 20, 1972 [1973], 23 U.S.T. 3813. Also, see, Operating Agreement Relating to the International Telecommunications Satellite Organization (Intelsat), August 20, 1971 [1973], 23 U.S.T. 4091.

provide transponders for multinational corporations, video networks and other entities wanting their own private network between the United States and Europe, has brought an outcry from an Intelsat official that a private Atlantic satellite network would threaten the integrity of Intelsat's global system and would be in violation of the Intelsat treaties.[9] Inmarsat, the International Maritime Satellite Organization,[10] is similar to Intelsat but is an international organization which provides the space segment for maritime satellite communications. Interestingly, both organizations allow a signatory to the operating arrangements to be a private entity, such as Comsat. If other private entities become involved with activities whereby it may be competitively necessary to receive information from Comsat as such a signatory, some legal prescription to that effect may be necessary.[11] Another example of potential conflict of roles the U.S. Government might be required to perform under international commitment and one that might emerge as in the best interests of an activity taken over by private industry could surface if weather satellites are sold to such private interests. The United States as a party to the Convention of the World Meteorological Organization[12] is a member of the international organization, the purpose of which are:

PURPOSES

The purposes of the Organization shall be

(a) To facilitate worldwide cooperation in the establishment of networks of stations for the making of meteorological observations or other geophysical observations related to meteorology and to promote the establishment and maintenance of meteorological centers charged with the provision of meteorological services;

(b) To promote the establishment and maintenance of systems for the rapid exchange of weather information;

(c) To promote standardization of meteorological observations and to ensure the uniform publication of observations and statistics;

(d) To further the application of meteorology to aviation, shipping, agriculture, and other human activities; and

(e) To encourage research and training in meteorology and to assist in coordinating the international aspects of such research and training.

CUSTOMARY INTERNATIONAL LAW

Even in the absence of any of the treaties discussed above, there has been a continuous flow of international decisions and practices to support the international principle of liability of a nation concerning acts carried out in its own territory that have an adverse

[9] *The Washington Post*, March 31, 1983.
[10] Done on September 3, 1976[1979], 31 U.S.T.1
[11] See, 48 Fed. Reg. 8462 (March 1, 1983) concerning the problem of Comsat relaying information to manufacturers in the United States of Earth station equipment.
[12] Done on October 11, 1947 [1950, 1 U.S.T. 281.

affect on the territory of another nation. [13] While this is not a fully settled point in international law, it would seem that an instance in which an activity instigated within a nation's territory and which is intended to be carried out over the territory of another nation, even if that first nation is legally entitled to do so, bolsters the possible application of this principle in the event of adverse consequences to that other nation's territory.

SOME UNRESOLVED INTERNATIONAL LEGAL PROBLEMS

If private industry supplants the Government in the conduct of certain space operations, the private sector could become more directly embroiled in a number of outstanding international controversies. It might well necessitate coordinating legal and foreign policy positions vis-a-vis the Government. Points of dissention exist with respect to the legal nature of the space environment itself or portions of it, national rights with reference thereto, and/or particular activities themselves either in their space contact or their effects on the Earth. Further complication is found in an intermeshing of many of these elements. Perhaps, much of the legal controversy can be attributed to the developed/developing nations dichotomy.

The delimitation of outer space

"The problem of whether and how to define outer space, particularly where to draw its lower limit and thus to distinguish it from airspace, belongs, without any doubt, to the oldest and most discussed questions of the law of outer space and its doctrine." [14] At the crux of this issue is the fact that different legal regimes and rights exist for airspace and outer space. Airspace is subject to the sovereign claim of the territory above it; outer space is not subject to any claim of sovereignty. Without a certain demarcation between these two regimes various degrees of legal uncertainty are raised, particularly as to activities that occur in both spheres. For example, in spite of administrative interpretation that the Space Shuttle is not an aircraft, there is an expression of opinion by some legal commentators that as a matter of law the Space Shuttle must be considered an aircraft while functioning in navigable airspace. [15]

The geostationary orbit

Closely related to the demarcation issue is the problem of the geostationary orbit—the equatorial orbit at which a satellite takes 24 hours to circle the Earth so that it is stationary as viewed from Earth, at an altitude of approximately 36,000 km. [16] Claims have been advanced to rights of sovereignty over certain segments of the geostationary orbit, and thereby a limited area of outer space, in

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[13] See, for example, *The Trail Smelter* case (*United States* v. *Canada*), 3 U.S.R.I.A.A. 1938 (1941); *The Corfu Channel* case [1949] I.C.J. 4; *The Lake Lannoux* case, 12 U.N.R.I.A.A. 281 (1957); and Nanda, *The Establishment of International Standards for Transnational Injury*, 60 Iowa L. Rev. 1089 (1975).

[14] Kopal, *The Question of Defining Outer Space*, 8 J. Space L. 154(1980).

[15] Robinson, *Private Management and Operation of the Space Shuttle: Some Legal Problems Related to Market Entry*, 13 Akron L. Rev. 601, 607 (1980).

[16] Office of Technology Assessment, *Solar Power Satellites* (OTA-E-144, August 1981), at 296 (Glossary).

favor of individual states located below such segments. The so-called Bogota Declaration [17] states in part: "There is no definition of outer space that is valid and satisfactory for the international community such as might be cited to support the argument that the geostationary orbit is included in outer space." The equatorial States basically use the stance represented by the New International Economic Order to substantiate their claim of sovereignty to such orbit as a natural resource. [18] The United States has, of course, rejected such a claim on scientific and legal grounds. [19] Yet, this legal issue subsists, accentuated by the practical reality that by far most communications satellites are those stationed in such orbit. [20]

Direct television broadcasting

The international community has not yet been able to formulate an international agreement on direct television broadcasting (whereby a broadcast goes from the satellite into a home receiver without any intervening relay action). The international issue here is open dissemination of ideas and information. Some States regard it as potentially introducing repugnant ideas into their territory. "The free transmission and reception of information is perceived differently in States possessing differing degrees of development and different ideological motivations." [21] The latest principles (which are not binding) can be found in an Annex to a General Assembly Resolution adopted in December 1982:

A. PURPOSES AND OBJECTIVES

1. Activities in the field of international direct television broadcasting by satellite should be carried out in a manner compatible with the sovereign rights of states, including the principle of nonintervention as well as with the right of everyone to seek, receive and impart information and ideas as enshrined in the relevent United Nations instruments.

2. Such activities should promote the free dissemination and mutual exchange of information and knowledge in cultural and scientific fields, assist in educational, social and economic development, particularly in the developing countries, enhance the qualities of life of all peoples and provide recreation with due respect to the political and cultural integrity of states.

3. These activities should accordingly be carried out in a manner compatible with the development of mutual understanding and the strengthening of friendly relations and cooperation among all states and peoples in the interest of maintaining international peace and security.

B. APPLICABILITY OF INTERNATIONAL LAW

4. Activities in the field of international direct television broadcasting by satellite should be conducted in accordance with international law, including the Charter of the United Nations, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, of 27 January 1967, the relevant provisions of the International Telecommu-

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[17] Declaration of the First Meeting of Equatorial Countries, signed on Dec. 3, 1976 by Columbia, Congo, Ecuador, Indonesia, Kenya, Uganda, Zaire, and Brazil (as an observer). 6 J. Space L. 193 (1978).

[18] E.g., see G.A. Res. 2692 (XXV) and G.A. Res. 3281 (XXV).

[19] U.S. Department of State, *Digest of United States Practice in International Law 1978* (1980), at 1189.

[20] Office of Technology Assessment, *Civilian Space Policy and Application*. OTA-ST1-177, June 1982, at 47.

[21] C.Q. Christol, *The Modern International Law of Outer Space* (1982), at 607.

nication Convention and its Radio Regulations and of international instruments relating to friendly relations and cooperation among states and to human rights.

C. RIGHTS AND BENEFITS

5. Every State has an equal right to conduct activities in the field of international direct television broadcasting by satellite and to authorize such activities by persons and entities under its jurisdiction. All states and peoples are entitled to and should enjoy the benefits from such activities. Access to the technology in this field should be available to all states without discrimination on terms mutually agreed by all concerned.

D. INTERNATIONAL COOPERATION

6. Activities in the field of international direct television broadcasting bv satellite should be based upon and encourage international cooperation. Such cooperation should be the subject of appropriate arrangements. Special consideration should be given to the needs of the developing countries in the use of international direct television broadcasting by satellite for the purpose of accelerating their national development.

E. PEACEFUL SETTLEMENT OF DISPUTES

7. Any international dispute that may arise from activities covered by these principles should be setttled through established procedures for the peaceful settlement of disputes agreed upon by the parties to the dispute in accordance with the provisions of the Charter of the United Nations.

F. STATE RESPONSIBILITY

8. States should bear international responsibility for activities in the field of internatinal direct television broadcasting by satellite carried out by them or under their jurisdiction and for the conformity of any such activities with the principles set forth in this document.

9. When international direct television broadcasting by satellite is carried out by an international intergovernmental organization, the responsibility referred to in Paragraph 8 above should be borne both by that organization and by the states participating in it.

G. DUTY AND RIGHT TO CONSULT

10. Any broadcasting or receiving state within an international direct television broadcasting satellite service established between them requsted to do so by any other broadcasting or receiving state within the same service should promptly enter into consultations with the requesting state regarding its activities in the field of internatinal direct television broadcasting by satellite, without prejudice to other consultations which these states may undertake with any other state on that subject.

H. COPYRIGHT AND NEIGHBORING RIGHTS

11. Without prejudice to the relevant provisions of international law, states should cooperate on a bilateral and multilateral basis for protection of copyright and neighboring rights by means of appropriate aggreements between the interested states or the competent legal entities acting under their jurisdiction. In such cooperation they should give special consideration to the interests of developing countries in the use of direct television broadcasting for the purpose of accelerating their national development.

I. NOTIFICATION TO THE UNITED NATIONS

12. In order to promote international cooperation in the peaceful exploration and use of outer space, states conducting or authorizing activities in the field of international direct television broadcasting by satellite should inform the Secretary General of the United Nations, to the greatest extent possible, of the nature of such activities. On receiving this information the Secretary General should disseminate it im-

mediately and effectively to the relevant specialized agencies as well as to the public and the internationl scientific community.

J. CONSULTATIONS AND AGREEMENTS BETWEEN STATES

13. A state which intends to establish or authorize the establisment of an international direct television broadcasting satellite service shall without delay notify the proposed receiving state or states of such intention and shall promptly enter into consultation with any of those states which so requests.

14. An international direct television broadcasting satellite service shall only be established after the conditions set forth in paragraph 13 above have been met and on the basis of agreements and/or arrangements in conformity with the relevant instruments of the International Telecommunication Union and in accordance with these principles.

15. With respect to the unavoidable overspill of the radiation of the satellite signal, the relevant instruments of the International Telecommunication Union shall be exclusively appplicable.

Remote sensing

There has also been a failure internationally to agree on principles governing remote sensing (observing conditions on the Earth from a satellite), or even to agree on a working definition thereof. Basically, the dispute involved is the position of the sensed States (which, it seems, tend to usually be complaining developing nations) that there be some form of prior consent and that they have some rights concerning the information obtained and how it is distributed. [22]

Use of nuclear power sources

The use of nuclear power sources in outer space is another object of legal dispute, particularly on the safety and environmental concerns. While covered to some extent by the existing space treaties, a new agreement in the form of supplementation on areas as consultation, notification, emergency assistance, and liability and recovery of damages is yet to be agreed on. [23]

Common heritage of mankind

The developing nations believe that the provision in Article I of the Outer Space Treaty that outer space "shall be the province of mankind" articulates the "common heritage of mankind" concept. [24] Additional support is gleaned from the specific provision in the recently proposed Moon Treaty providing that the natural resources of the Moon "are the common heritage of mankind," and the recently advanced Law of the Sea Treaty declaring the area and its resources as the common heritage of mankind. [25] "The common heritage of mankind doctrine applies to the use of space by the placement of a craft in a specific location." [26]

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[22] Id., at 732–733.

[23] Id., at 765–810. Also, see 1982 Report of the U.N. Committee on the Peaceful Uses of Outer Space, at 8–9.

[24] Okolie, *Legal Interpretation of the 1979 United Nations Treaty Concerning the Activities of Sovereign States on the Moon and Other Celestial Bodies Within the Meaning of the Concept of Common Heritage of Mankind*, in Int'l Inst. of Space Law of the Int'l Astronautical Fed'n Proceedings of the Twenty-Third Colloquium on the Law of Outer Space 61, 64 (1981).

[25] Art. 136; 21 I.L.M. 1293 (1982).

[26] Tennan, *Outer Space: A Preserve for All Mankind*, 2 H. J. Int'l L. 145, 153 (1979)

> For developing countries, "common heritage" means common ownership of the resources and majority control over their disposition. This translates into insistence that no single country, or entity under its control, has the independent right to use the commonly owned resource. Access to the resources must first be approved by the international community on the basis of one nation-one vote. As a result, the developing countries would collectively control who is allowed to exploit and use the resource. The concept of the "common heritage of mankind" does not, in the view of the Third World, recognize that industrialized countries with space technology should have a greater voice in regulating outer space resource technology. [27]

In spite of a contrary legal posture by the United States and most legal commentators that the common heritage concept does not amount to an international legal doctrine, and which has no fixed meaning or binding effect, it does, at least, arguably raise some degree of apprehension on the certainty or recognition of the legal effects attached or attachable to acts or activities in outer space.

Present Domestic Regulatory Schemes

U.S. statutes and regulations that may be applicable to private activity in or concerning outer space are numerous and complex. A theoretical examination may be misleading because the application of each or any of them, in whole or in part, would depend on the numerous factors involved in an actual situation. There does not seem to be any existing strictly designed framework which either specifically disallows or fosters "pure" private commercialization of space or space activity. Congress, in the statutory creation of Comsat, a nongovernmental, forprofit corporation, to act for the United States in establishing and participating in an international, commercial communications satellite system, has expressly reserved the right to repeal, alter or amend this enabling legislation at any time, [28] besides providing for such things as the powers of the corporation [29] and annual reporting to the Congress on its activities and accomplishments. [30]

An attempt will be made here to point out some areas of regulation which appear to be adverse to or an encouragement of either private commercial actions in some specifically related activity or in general. Seemingly, more of these provisions appear to be of an adverse nature, but this does not necessarily mean that such private endeavors would be less legally feasible than other kinds of private commercial undertakings, or that the private bar could not meet the challenge of accomplishing an intended effect despite such adversity.

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[27] Dula, *Free Enterprise and the Proposed Moon Treaty*, 2 H. J. Int'l L. 3, 19-20 (1979).
[28] 47 U.S.C. §731.
[29] 47 U.S.C. §735.
[30] 47 U.S.C. §744.

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FEDERAL DOMINANCE

The legal question to be addressed here is whether by virtue of the National Aeronautics and Space Act of 1958, [31] any and all private space activity can only be carried out under the aegis of NASA? With respect to civilian space activity, the act provides in part that activities in space "shall be the responsibility of, and shall be directed by, a civilian agency exercising control over aeronautical and space activities sponsored by the United States..." [32] "Aeronautical and space activities" is defined as "(A) research into, and the solution of, problems of flight within and outside the Earth's atmosphere, (B) the development, construction, testing, and operation for research purposes of aeronautical and space vehicles, and (C) such other activities as may be required for the exploration of space. . . ." [33] One legal commentator has concluded that an activity such as private aerospace transportation would not be encompassed thereby because it would be operated for profit and not for research or exploration purposes, and that it is not "sponsored" by the United States. [34] Yet, it would seem that a strong argument can be made to support the position that all civilian space activity could fall within the purview of the act. First, the legislative history of the act appears to support a contention that the only activities excludable from potential coverage were those "aeronautical" activities in existence in 1958, and that exploitation activities as well as exploration ones are included. The conference report, in discussing definitions, states in part: "The purpose is to make clear that the act is concerned primarily with research, development, and exploration. The use of the word "activities" is intended to be broad in the area of outer space because no one can predict with certainty what future requirements may be. . . . These activities would include scientific discovery and research not directly related to travel in outer space but utilizing outer space, and the development of resources which may be discovered in outer space." [35] Second, sponsorship would arguably include other actions or situations than where there is Federal funding and substantial Federal supervision. The plain meaning includes "one who assumes responsibility for some other person or thing." [36] As previously discussed, the United States is internationally responsible for private space activity, and Congress has expressly declared responsibility for all activities in space in the act. [37]

Another area of Federal dominance appears to be NASA's authority to initiate and carry out a program of research, technology, monitoring, and other appropriate activities directed to understanding the physics and chemistry of the upper atmosphere. [38]

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[31] 42 U.S.C. §2451 et seq.
[32] 42 U.S.C. §2451 (b)
[33] 42 U.S.C. §2452(1)
[34] Dula, *Regulation of Private Commercial Space Activities*, 23 Jurimetrics, 156, 160-163 (1983).
[35] H. Rep. No. 1758, 85th Cong., 2d Sess (1958); 1958 U.S. Code Cong. and Admin. News 3186, 3192-3193.
[36] Webster's New Collegiate Dictionary (1973).
[37] 42 U.S.C. §2451 (b)
[38] 42 U.S.C. §2483 (b)

NASA has taken a seemingly broader approach through "Joint Endeavor Agreements" a form of NASA/industry relationship to encourage private sector participation in certain research. [39]

MULTIPLE FEDERAL AGENCY JURISDICTION

Various, overlapping and perhaps conflicting jurisdiction over certain space activities may be exercised by a number of Federal administrative agencies. Private rocket launching is perhaps the prime example. The Federal Aviation Act of 1958 authorizes regulations to, inter alia, prevent collision between aircraft and airborne objects. [40] The FAA has promulgated the following with regard to operating limitations and notice requirements for unmanned rockets: [41]

§101.23 Operating limitations.

No person may operate an unmanned rocket—

(a) In a manner that creates a collision hazard with other aircraft;

(b) In controlled airspace;

(c) Within five miles of the boundary of any airport;

(d) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(e) At any altitude where the horizontal visibility is less than five miles;

(f) Into any cloud;

(g) Within 1,500 feet of any person or property that is not associated with the operations; or

(h) Between sunset and sunrise.

(Sec. 6(c), Department of Transportation Act (49) U.S.C. 1655(c))

[Doc. No. 1580, 28 FR 6722, June 29, 1963, as amended by Amdt. 101-4, 39 FR 22252, June 21, 1974.]

§101.25 Notice requirements.

No person may operate an unmanned rocket unless, with 24 to 48 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest the place of the intended operation:

(a) The names and addresses of the operators.

(b) The number of rockets to be operated.

(c) The size and weight of each rocket.

(d) The maximum altitude to which each rocket will be operated.

(e) The location of the operation.

(f) The date, time, and duration of the operation.

(g) Any other pertinent information requested by the ATC facility.

The Department of State might assert some jurisdiction based on its authority under the Arms Export Control Act [42] and its accompanying regulations concerning launch vehicles and rockets. [43] NASA could probably assert jurisdiction under the broad sweep of the National Aeronautics and Space Act, [44] particularly if NASA installations are used. [45] The FCC could probably assert jurisdic-

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[39] See, Office of Technology Assessment, *Civilian Space Policy and Applications*, OTA-STI-177, June 1982, at 232-234.

[40] 49 U.S.C. §1348 (c)

[41] Title 14, Code of Federal Regulations (CFR).

[42] 22 U.S.C. §2778.

[43] 22 CFR §121.01

[44] 42 U.S.C. §2451 et seq.

[45] 14 CFR, Part 1204, Subpart 10. If launching pads of the Air Force are involved, the Department of the Air Force may also be an interested agency.

tion by virtue of the communications frequencies required in a launching under its authority granted by the Federal Communications Act of 1934.[46] A "rocket" also falls within the definition of "destructive device" under the firearms provisions of the Criminal Code[47] and, therefore, some assertion of jurisdiction might be made by the Bureau of Alcohol, Tobacco and Firearms. If special taxes are involved, the Internal Revenue Service also might step in.

Besides this potential Federal governmental involvement, it is conceivable that some of the States might assert some jurisdiction if, for example, the launching takes place within that State or the private entity conducting the launching is organized under that State's laws, and the State(s) have relevant legislation such as dealing with rules of conduct for aeronautical and/or hazardous activities.[48] It is even possible that certain local laws and regulations might be applicable. Related activities could also be covered by a myriad of laws, for example, Federal, State, and local labor laws concerning the rocket launching personnel.

PATENTS

There appears to be a great deal of confusion concerning the rights to inventions which have significant utility in the conduct of space activities, particularly where some contract exists with NASA. At the very least, it would seem that a private entity would or might be subjected to a more protracted and cumbersome procedure in obtaining such a patent than with other commercial inventions. The pertinent provisions in section 305[49] of the National Aeronautics and Space Act of 1958 read as follows:

PATENT APPLICATION

(c) No patent may be issued to any applicant other than the Administrator for any invention which appears to the Commissioner of Patents to have significant utility in the conduct of aeronautical and space activities unless the applicant files with the Commissioner, with the application or within thirty days after request therefore by the Commissioner, a written statement executed under oath setting forth the full facts concerning the circumstances under which such invention was made and stating the relationship (if any) of such invention to the performance of any work under contract of the Administration. Copies of each such statement and the applications to which it relates shall be transmitted forthwith by the Commissioner to the Administrator.

ISSUANCE OF PATENT TO APPLICANT; REQUEST BY ADMINISTRATOR; NOTICE; HEARING; DETERMINATION; REVIEW

(d) Upon any application as to which any such statement has been transmitted to the Administrator, the Commissioner may, if the invention is patentable, issue a patent to the applicant unless the Administrator, within ninety days after receipt of such application and statement, requests that such patent be issued to him on behalf of the United States. If, within such time, the Administrator files such a request with the Commissioner, the Commissioner shall transmit notice thereof to the applicant, and shall issue such patent to the Administrator unless the applicant within thirty days after receipt of such notice requests a hearing before a Board of Patent Interferences on the question whether the Administrator is entitled under

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[46] 47 U.S.C. §151 et seq.
[47] 18 U.S.C. §921 et seq.
[48] For example, the Code for Unmanned Rockets, N.F.P.A 1122L. Dula, *Regulation of Private Commercial Space Activities*, 23 Jurimetrics 156, 175 (1983)
[49] 42 U.S.C. §2457(c)(d)(e).

this section to receive such patent. The Board may hear and determine, in accordance with rules and procedures established for interference cases, the question so presented, and its determination shall be subject to appeal by the applicant or by the Administrator to the Court of Customs and Patent Appeals in accordance with procedures governing appeals from decisions of the Board of Patent Interferences in other proceedings.

FALSE REPRESENTATIONS; REQUEST FOR TRANSFER OF TITLE TO PATENT; NOTICE; HEARING; DETERMINATION; REVIEW

(e) Whenever any patent has been issued to any applicant in conformity with subsection (d) of this section, and the Administrator thereafter has reason to believe that the statement filed by the applicant in connection therewith contained any false representation of any material fact, the Administrator within five years after the date of issuance of such patent may file with the Commissioner a request for the transfer to the Administrator of title to such patent on the records of the Commissioner. Notice of any such request shall be transmitted by the Commissioner to the owner of record of such patent, and title to such patent shall be so transferred to the Administrator unless within thirty days after receipt of such notice such owner of record requests a hearing before a Board of Patent Interferences on the question whether any such false representation was contained in such statement. Such question shall be heard and determined, and determination thereof shall be subject to review, in the manner prescribed by subsection (d) of this section for questions arising thereunder. No request made by the Administrator under this subsection for the transfer of title to any patent, and no prosecution for the violation of any criminal statute, shall be barred by any failure of the Administrator to make a request under subsection (d) of this section for the issuance of such patent to him, or by any notice previously given by the Administrator stating that he had no objection to the issuance of such patent to the applicant therefor.

The courts have held that when an invention is developed under contract with NASA and subsequently reduced to practice outside the contract, the invention can be considered to have been made as a result of the contract. [50] "Contract" is broadly defined as including "any actual or proposed contract, agreement, understanding, or other arrangement, and includes any assignment, substitution of parties, or subcontract executed or entered into thereunder. . . ." [51] However, it appears that NASA has taken a restrictive view of this provision and not all actions which literally might fall within it have been so included, for example, joint endeavors, in order to maintain private incentive and initiative. [52]

COMSAT

Comsat was created as a private corporation "subject to appropriate Government regulation" as the U.S. participant in a global communications satellite system, with such entity to be the U.S. representative in Intelsat and Inmarset. [53] The existence of this private commercial entity has at least two possible legal inhibitions to the entry of other commercial endeavors either using such communication services or perhaps dependent on the inner workings of these two international organizations. The enabling act provides: "It is not the intent of Congress by this act to preclude the use of the communications satellite system for domestic communication services where consistent with the provisons of this act nor to pre-

[50] *Hummer* v. *Administrator of the National Aeronautics and Space Administration* 500 F.2d 1383, 1388 (Cust. & Pat. App. 1974).

[51] 42 U.S.C. §2457(j)(2).

[52] See NASA Memo of June 19, 1979 from Assistant General Counsel for Patent Matters to General Counsel on "Applicability of Section 305 of the Space Act to Joint Endeavors." Such is actually incorporated in the Joint Endeavor Agreements.

[53] 47 U.S.C. §701 et seq.

clude the creation of additional communications satellite systems, if required to meet unique governmental needs or it is otherwise required in the national interest." [54] Thus, it would seem that for a private commercial entity to use the system for domestic communications services in addition to compliance with general provisions of law it would be confined to activities "consistent" with this act. To establish an additional communications system, a potential entrant would have to show that such is required to meet unique governmental needs or in the national interest. Further, by virtue of Comsat's privileged position in Intelsat and Inmarsat, it would be privy to the workings or direction of thinking of those organizations at an earlier time than other, competing U.S. commercial entities. In recent regulations of the FCC amending rules and policies to conform with the Inmarsat system, the following issue is stated (but not discussed as the rule purportedly covers this point): "[S]ignatories of other countries in the Inmarsat Organization provide to their manufacturers important Inmarsat documents concerning ship earth station specifications which are not made available by the U.S. Signatory, Comsat, to its manufacturers. As a result, manufacturers in other countries have the opportunity to examine these documents in draft form and have an early knowledge of Inmarsat thinking. This gives them a competitive advantage in their business activities with the U.S. manufacturers." [55]

LAWS OF GENERAL APPLICABILITY

In addition to any specific regulatory restrictions, laws of a more general nature may apply to the entry into and/or conduct of operations of space commercial ventures. For example, anticompetitive behavior by and between commercial entities would be subject to the Federal (and State) antitrust laws. One of these laws, the Sherman Act, [56] prohibits contracts, combinations or conspiracies that unreasonably restrain trade, and might well be relevant in such action as the formation of any joint ventures or teaming arrangements. [57] On the other hand, some laws of a general nature may be considered favorable to such potential operations, for example, some of the tax laws are considered for such activities as research and development expenditures and venture capital investments in new technology-based firms. [58]

Private Industry Perceptions

In the light of the previously discussed international situation and domestic regulatory framework, it would seem that private industry might make certain arguments to help establish a posture that too many obstacles or unknowns exist to encourage the commercial risk and expense in most instances by private undertaking.

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[54] 47 U.S.C. §701 (d)

[55] 48 Fed. Reg. 8460, 8462, March 1, 1983.

[56] 15 U.S.C. §1 et seq.

[57] See, Donald L. Flexner, *The Impact of Antitrust on Commercial Ventures to Exploit Space Technology*, in ALI-ABA Conference Materials, *International Conference on Doing Business in Space: Legal Issues and Practical Problems* (1981), at 305.

[58] See, Report of the National Academy of Public Administration, *Encouraging Business Ventures in Space Technologies* (May 1983), at 35–36.

1. Not only are a number of international law issues concerning space and space activities controversial and unsettled, private rights would be subject to negotiation or even extinguishment under current or future international negotiation pressures.

2. Present U.S. statutory provisions emphasize public (NASA) participation in most space activities or rights thereto, and leave little encouragement or incentive for viable private action.

3. An administrative morass exists concerning private launchings of rockets making it extremely difficult and burdensome to effectuate the necessary clearances in a timely and practical fashion.

4. The establishment by the Congress of a quasi-private entity with certain inherent competitive advantages, including initial access to certain participation and information, presents certain possible commercial impediments to others.

What does private industry want? As a legal optimum, private industry possibly might contend that there should be an express national space policy which includes specific roles, goals or objectives for private commercial ventures, with the minimum amount of Government regulation. Other desires might include Government financial incentives, including such items as direct subsidies, loan guarantees, tax breaks, and limits on liability. If there is to be some Federal agency oversight, it should preferably be by only one. If multiple agencies need be involved, there at least should be one lead agency for industry to deal with and which would be responsive to it. Exemptions from certain general regulatory laws, such as the antitrust laws, should be provided. Proprietary commercial rights should be retained for and by private actions and inventions. Government insurance should be available in the event that private insurers fail or refuse to provide adequate coverage for the risks involved. The Government should provide protection by way of a grandfather clause if future international agreements are negotiated affecting existing private U.S. rights. [59]

Some Recent Legislative Proposals

While a series of earlier proposals in Congress seemed primarily involved with providing investment capital and establishing the necessary business conditions to attract industries to use the space environment to manufacture products and provide services through the creation of a Space Industrialization Corporation to serve as an investment bank, [60] so far in the 98th Congress [as of May 3, 1983] proposals generally seem to involve three tacts, sometimes treated separately or in tandem. The legislation introduced so far that seems to be the broadest in scope is H.R. 1011 (98th Cong.), the "Space Commerce Act." Its stated findings and purpose are:

FINDINGS AND PURPOSE

SEC. 2. (a) FINDINGS.—The Congress finds and declares that—

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[59] Precedents in a number of these areas with regard to other areas of technology are pointed out in Office of Technology Assessment, *Civilian Space Policy and Applications*, OTA-STI-177, June 1982, at 268-270.

[60] E.g., H.R. 564, 97th Cong.; H.R. 2337, 96th Cong.; and H.R. 14297, 95th Cong. Also, see, Fuqua, *Space Industrialization: Some Legal and Policy Considerations for Private Enterprise*, 8J. Space L. 1 (1980)

(1) the peaceful use of outer space continue to be of great value and to offer benefits to all mankind;

(2) civilian applications of space technology have achieved a significant level of commercial and economic activity, and offer the potential for growth in the future, particularly in the United States;

(3) new and innovative equipment and services are being sought, created, and offered by entreprenuers in telecommunications, information services, and remote sensing technology;

(4) the private sector in the United States has the capability of developing and providing private satellite launching and associated services that would supplement the launching and associated services now available from the United States Government;

(5) cost savings could accrue from the private sector developing and providing launching services;

(6) the development of such services would enable the United States to better compete with the launching services now being developed by foreign countries, thereby contributing to the national interest and economic well- being of the United States;

(7) commercial provision of such services is not inconsistent with the national security interests of the United States;

(8) the United States should encourage and, to the extent reasonable necessary, regulate private sector launching and associated services to provide for the national security and public safety and to carry out the obligations of the United States under international treaties affecting the use of space;

(b) PURPOSE.—It is the purpose of this Act to—

(1) encourage the development of the United States private sector of capabilities for providing launching and associated services;

(2) provide the necessary regulation by the Federal Government to ensure public safety and national security and to carry out obligations of the United States, such as liability for damage from space objects, under applicable international treaties and agreements affecting the use of space;

(3) stimulate private sector applications of Government-developed space technology; and

(4) promote further economic growth and entreprenuerial activity in utilizing the space environment for peaceful activities.

A detailed licensing procedure for a private launching is set forth, and the Secretary of Commerce would be responsible for carrying out the act and providing a designated point of contact within that Department for the licensing procedure as well as to coordinate and facilitate all Federal actions pertinent to private sector launches. The obtaining of liability insurance is a prerequisite for such launchings. The act also would establish a Commercial Space Study Commission to "conduct a study of the direction of future Government involvement in, support of, and regulation of private sector commercial activity in outer space." A similarly motivated bill has been introduced in the Senate, S. 560, the "Private Satellite Launching Authorization Act of 1983," with similar findings, purpose, and policy. It, however, would make the Administrator of the FAA in charge of a licensing procedure (not set forth in the proposal), and also to promulgate regulations concerning safety standards for the design and construction of space launch vehicles and for their launching, as well as liability insurance requirements. A separate bill, S. 955, the "National Commission on Space Act" would establish a National Commission on Space (and covers this aspect in greater detail than H.R. 1011), whose functions, in part, would include:

FUNCTIONS OF THE COMMISSION

SEC. 6. (a) The Commission shall make a comprehensive investigation of exisiting and proposed space activities in the United States in order to assess their adequacy in meeting the present and future needs of the Nation. Such study shall include—

(1) a review of the known and possible economic, social, environmental, foreign policy, and national security needs of the United States, and methods by which space science, technology, and applications initiatives might address those needs;

(2) a review of the adequacy of the Nation's public and private capability in space science, technology, and applications;

(3) a review and assessment of present issues and issues that may arise as space research, technology development, and applications are utilized to meet future national needs; and

(4) an analysis of the findings of the reviews specified in paragraphs (1) through (3) of this subsection, and options and recommendations for a national space policy and program plan.

(b) Issues to be considered pursuant to subsection (a)(3) of this section shall include—

(1) the adequacy of the National Aeronautics and Space Act of 1958 (42 U.S.C. 2451 et seq.) to serve as the basis for future national space policy;

(2) alternative roles and relationships of the civilian and national security space programs;

(3) alternative roles and relationships of the private and public sectors in national space efforts.

(4) the suitability of existing Federal organizational arrangements to carry out future governmental responsibilities in space research, technology development, and applications;

(5) the opportunities for, and barriers to, private sector utilization of the space environment and participation in national space programs;

(6) the methods, occasions, and circumstances under which the Nation should pursue a permanent presence in space; and

(7) considerations involving international cooperation and competition in the utilization of the space environment.

(c) Options and recommendations submitted in accordance with subsection (a)(4) of this section shall include an estimate of costs and time schedules, institutional requirements, and statutory modifications necessary for implementation of such options and recommendations.

Another tact can be found in H.R. 478 (98th Cong.), the "National Space Policy of 1983" (with 64 cosponsors), which is designed to establish the national space policy of the United States. Two of the stated findings are:

(10) the successful development and use of the space environment for scientific and applied purposes depends on continued research and development efforts conducted by the government and private sector; and

(11) the productive development and use of the space environment requires new policies, procedures, and institutional arrangements that encourage initiative by, and use the innovative capabilities of, the private sector.

Two of the declared statements of policy are:

(9) the benefits of space program research to terrestial applications will be maximized by rapid dissemination of information concerning such programs to appropriate public and private bodies; and

(10) the development of space capabilities and systems by the private sector to produce economic benefits to, and to enhance the technological position of, the United States, will be encouraged.

In addition, a number of bills have been introduced which provide, in effect, that the ownership or management of any civil land remote system or meteorological satellite system, or their associated ground systems, cannot be transferred to the private sector

without the approval of the Congress.[61] On April 26, 1983, the House of Representatives passed the NASA authorization bill, H.R. 2065 (98th Cong), to which just such a provision had been added.

Some Possible Future Legal Problems

Private sector involvement in space activities will probably prompt numerous legal problems, particularly as the space technology advances and more human activity takes place in outer space.

CLAIMS

A number of areas may be involved with potential damage to property or injury to persons.

Safety

A regulatory safety regime may be necessary, covering vehicle safety and space worthiness, competency of crews, and design of systems to insure maximum safety of flights and return.[62] The possibility of health emergencies may arise, including Earth quarantines.[63]

Liability

Potential high-technology catastrophic accidents could pose problems. Except for nuclear accidents, NASA's coverage for users of the Space Shuttle and some relatively minor statutes, there is no comprehensive statute dealing with manmade accidents.[64] Responsibilities, obligations, funding, contributions, and claim procedures are the kinds of matters that may need clarification. Other potential claims for liability might arise, such as products liability,[65] which may require resolution mechanisms.

Insurance

Space activity involves new risks, without customary, Earth-oriented perils.[66] Present law covering and permitting NASA to allocate third-party liability risks among the users of the Space Shuttle[67] may not be a viable precedent in other areas, and creative insurance and re-insurance schemes may be called for.[68] At some point, Government participation and/or oversight may be necessary.

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[61] See, e.g., H.R. 1958, H.R. 2507, S. 480 (98th Cong.)

[62] Stewart, Jr., *Emerging Patterns of a Private International Space Law Regime—Evolutionary or Revolutionary?* IISL, *Proceedings of the Twenty-Third Colloquium on the Law of Outer Space* (1980), at 201, 202.

[63] Robinson, *Earth Exposure to Martian Matter: Back Contamination Procedures and International Quarantine Regulations*, 15 Colum. J. Transnat'l L. 17 (1976). Present regulations, 14 CFR, Part 1211, are limited in scope and only apply to NASA missions that come in contact with the atmosphere of celestial bodies.

[64] Dembling, *On Doing Business in Space*, 20 Astronautics & Aeronautics 18, 176 (1982).

[65] See, Haanappel, *Products Liability in Space Law*, 2 Hous. J. Int'l L. 55 (1979)

[66] Banham, *Count-Up for Space Insurance*, the Journal of Space Insurance, January/February (1982)

[67] 42 U.S.C. § 2458 (b).

[68] Mossinghoff, *Managing Tort Liability in the Era of the Space Shuttle*, 7 J. Space L. 121, 126 (1979). Also, see, Margo, *Some Aspects of Insuring Satellites*, 1979 Ins L.J. 555 (1979)

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JURISDICTION

A great number of problems that are jurisdictional in nature may arise as more diverse commercial activities increase in space and larger numbers of persons spend greater time in that environment. As ownership, financing and participation becomes more multinational, that is, employing more and more citizens or business entities from different nations, as well as proprietary or registered bases in more than one nation or involving international organizations, it may become more difficult to ascertain what laws apply to diverse actions and even who is to make that kind of determination. For example, as satellite ownership becomes increasingly fragmented, "it becomes correspondingly difficult to associate particular treaty and statutory obligations (for example, coordination, tariffs, permissible business practices) with specific entities." [69] Not only may a conflict of law issue arise in any given instance, but questions as to the extraterritorial application of U.S. laws and even the U.S. Constitution may become issues. Certain assertions may even be made under international law. "If all persons in outer space—not merely astronauts and cosmonauts—are assimilated to the status of envoys of mankind and are the subject of international law, some inevitable collisions are perceived between the control of persons in space by the state of nationality and the individual assertion by such persons of internationally recognized human rights and fundamental freedoms." [70]

All sorts of possibilities may exist if analogies are made. Will there be the same sort of "genuine link," salvage, and search and seizure problems that now exist in maritime situations on the high seas? Will specific criminal offense treaties be necessary as has been prompted by crimes committed aboard aircraft?

CONCLUSION

Any ambitious scheme to promote private sector involvement in commercial activities in outer space presents a number of legal problems on several levels. The present regulatory scheme, both international and domestic, for the most part is operationally designed for national interest and responsibility. Any shift of such emphasis to a cross section of private control raises a potential realignment of rights and obligations between the United States and the international community, between the United States and such private sector entities, and between those entities themselves. Legal considerations are crucial on each strata. Adding to the legal complexity is the nature of the activity itself as well as the rapidly evolving technology involved. Great expenditures may be necessary, and high and unforeseen risks may enter the picture. Operational areas are not limited to the territorial confines of the United States, and the potential for calamitous consequences exists.

To facilitate action, among other things it may be necessary to: pinpoint the kinds and extent of commercial involvement that may

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[69] Smith and Rothblatt, *Geostationary Platforms: Legal Estates in Space*, 10 J. Space L. 31, 35 (1980).

[70] Glazer, *Domicile and Industry in Outer Space*, 17 Colum. J. Transnat'l L. 17 (1976).

be practically and politically possible; describe with great detail the form and content of any Government regulation, including a systematic approach as to who, what, when and where private action may be taken; and undertake a close examination as what new international controls may be prudent. Once significant private involvement is forthcoming, any developing legal framework will likely be ongoing. Novel legal problems will probably arise, calling perhaps for new and creative legal theories and enforcement mechanisms.

APPENDIX—SUMMARY OF SPACE COMMERCIALIZATION PROPOSALS

The number of commercial space proposals in areas ranging from expendable launch vehicles to space stations grows almost weekly. The following is a summary of those proposals which could be identified through April 30, 1983. Some are only in the conceptual stage, others are already operational.

In brief, the companies making proposals, according to commercial area, are as follows:

Expendable launch vehicles
- ARC Technologies (Dolphin)
- General Dynamics (Atlas-Centaur)
- Satellite Propulsion, Inc. (Liberty)
- SpaceTran/Martin Marietta (Titan 34D)
- Space Services, Inc. (Delta, Conestoga)
- Transpace Carriers Inc. (Delta)

Reusable space vehicles
- Pacific American Launch Systems (Phoenix)
- Transpace Inc. (Space Van)

Upper stages
- McDonnell Douglas (Payload Assist Module—PAM)
- Orbital Systems Corp. (Transfer Orbit Stage—TOS)

In-Orbit facilities/equipment
- Architects Equities, Inc. (Shuttle payload bay materials processing)
- Ball Aerospace (Shuttle payload bay materials processing)
- Fairchild (Leasecraft, free-flying module for power, telemetry, control, etc.)
- GTI (materials processing furnace—Agreement with NASA terminated)
- Space Industries (space station)

Materials processing experiments
- Battelle Columbus Laboratories
- Beckman Instruments
- Dupont
- EG&G
- Eli Lilly
- Honeywell
- Inco
- John Deere
- Johnson and Johnson/McDonnell Douglas
- Johnson Matthey
- Microgravity Research Associates
- Northrop
- Parker-Hannifan Corp.
- Robert Shaw Associates

A. E. Staley Manufacturing
Terra Mar
TRW
Union Carbide

Space Shuttle
Astrotech International (payload processing facilities at Kennedy Space Center)
Hughes Aircraft (satellite manufacturing and possible payload processing at KSC)
SpaceTran (purchase of a fifth orbiter)

Remote sensing satellite systems

Several companies have indicated interest in operating the existing Landsat system (space and/or ground segments) and possibly the NOAA weather satellites, but no formal proposals have been made at this time. In addition, one company, American Science and Technology, has proposed developing and launching its own remote sensing satellites although its proposal is not formal yet, either.

Existing NASA Mechanisms for Encouraging Commercial Space Activities

There are currently three types of agreements which NASA uses in facilitating Government/industry cooperation in commercial space endeavors: A cooperative agreement, a joint endeavor agreement, and a technical exchange agreement. [1] The differences between the three are slight, and which one is used for a particular activity depends primarily upon which NASA office is in charge of the agreement. For example, the joint endeavor and technical exchange agreements are used primarily for materials processing experiments—the former most often when an actual flight experiment is contemplated, the latter when experimentation primarily takes place on the ground. The term "cooperative agreement" was initially coined as part of NASA's international activities and denoted an agreement between NASA and another country in which no exchange of funds occurred. Its meaning has now been extended to commercialization activities between NASA and the private sector, such as the agreement with Orbital Systems Corp. for development of an upper stage.

Expendable Launch Vehicles/Upper Stages

There are currently four expendable launch vehicles (ELV's) in use in the United States: Titan, used primarily by the DOD and manufactured by Martin Marietta; Delta, used primarily by NASA and manufactured by McDonnell Douglas; Atlas, used by both NASA and DOD and manufactured by General Dynamics; and Scout, used primarily by NASA for very small payloads, and manufactured by LTV Aerospace. Proposals to commercialize the first three of these systems have already been made public. Martin Marietta, in conjunction with SpaceTran Inc., is actively marketing its Titan 34D vehicle, while General Dynamics is similarly marketing

[1] Information for this section is based on a meeting and subsequent telephone conversations with a NASA representative, April 1983.

its Atlas-Centaur. McDonnell Douglas has no plans at this time to market the Delta, although two other companies, Transpace Carriers Inc. and Space Services. Inc. have shown interest in this ELV. Both companies are holding discussions with McDonnell Douglas concerning their proposals, but no definitive arrangements have been made.

Three companies are in the process of developing their own ELV's: Space Services, Inc. is developing the Conestoga rocket based on Minuteman technology and has successfully completed one suborbital test flight; ARC Technologies of Redwood City, Calif. is developing the Dolphin which will be launched from the ocean rather than land, and is initially being developed as a suborbital sounding rocket; and Satellite Propulsion, Inc. of Beverly Hills, Calif. is considering development of an ELV called Liberty to compete with Atlas-Centaur.

There are also several upper stages used with the ELV's and/or with the Shuttle: the Payload Assist Module (PAM), developed and manufactured by McDonnell Douglas; the Inertial Upper Stage (IUS), developed under Government contract and manufactured by Boeing; Centaur, developed under Government contract and manufactured by General Dynamics with a new version for use with the Shuttle now in development; and the Transfer Orbit Stage (TOS) being developed privately by Orbital Systems Corp. under a cooperative agreement with NASA.

The following tables summarize the characteristics of the ELV's and upper stages that are being proposed for commercialization.

U.S. Expendable Launch Vehicles Proposed for Commercial Operations

Vehicle [1]	Manufacturer	Entity planning to commercialize	Fuel type	Payload weight to orbit, [2] comments
Dolphin	ARC Technologies	ARC Technologies	Hybrid	Suborbital. 500–2,000 lbs to 100–300 miles altitude. Vehicle being privately developed; may have orbital version later.
Liberty	Satellite Propulsion Inc.	Satellite Propulsion Inc.	Liquid	6,300 lbs to LEO (due east) 4,500 lbs to GTO. Vehicle being privately developed.
Atlas-Centaur	General Dynamics	General Dynamics	Cryogenic	5,200 lbs to GTO in 1983; improvements to 14,000 lbs to GTO planned. Developed under Government contract.
Conestoga	Space Services, Inc.	Space Services, Inc.	Solid	500 lbs to LEO (polar orbit). Vehicle being privately developed.
Delta 3910/3970 (with PAM)	McDonnell Douglas	TranSpace Carriers; Space Services, Inc.	Liquid	5,500 lbs to LEO. Delta 3910 can put 2,450 lbs in GTO. Delta 3920 can put 2,800 lbs in GTO. Vehicle developed under Government contract.

U.S. Expendable Launch Vehicles Proposed for Commercial Operations–Continued

Vehicle [1]	Manufacturer	Entity planning to commercialize	Fuel type	Payload weight to orbit, [2] comments
Titan 34D	Martin Marietta	SpaceTran/Martin Marietta	Liquid	31,000 lbs to LEO. Can put 5,600–6,000 lbs in GEO assuming satellite has own kick stage. Vehicle developed under Government contract.

[1] Launch vehicles typically have several different versions each with different capabilities. The version(s) listed here are those specifically for which commercialization proposals have been made.

[2] LEO is low Earth orbit. GEO is geostationary Earth orbit. GTO is geostationary transfer orbit, an eccentric orbit into which a payload is initially placed, after which an additional kick stage is used to circularize the orbit at GEO. Approximately half the payload weight to GTO is taken to GEO. All payload weights are in pounds (lbs).

Source: All data were obtained from the companies involved in manufacturing or commercializing the vehicle, or NASA.

U.S. Upper Stages

Vehicle	Manufacturer	Used in conjunction with	Fuel type	Payload to GEO	Comments
Centaur	General Dynamics	Shuttle [2]	Cryogenic	10,600 lbs. [2]	In development under Government contract. [2]
IUS	Boeing	Shuttle or Titan	Solid	5,000 lbs	In use, but failed its second launch in March 1983. Developed under Government contract.
PAM D	McDonnell Douglas	Shuttle or Delta	Solid	2,750 lbs. [1]	In Use.
PAM D II	McDonnell Douglas	Shuttle or Delta	Solid	3,500–3,900 lbs. [1]	In Development.
PAM A	McDonnell Douglas	Shuttle or Delta	Solid	4,400 lbs. [1]	Developed privately by McDonnell Douglas.
TOS	Orbital Systems Corp.	Shuttle	Solid	2,800–6,800 lbs.	In development. Being developed privatly by OSC.

[1] Indicates payload weight is to geostationary transfer orbit, not geostationary orbit (GEO).

[2] Centaur can also be used with Atlas and Titan, but the version here is the one in development for use with the Shuttle. The company also plans to develop a version with a 14,000 lb capability for planetary missions. Centaur can have a greater payload capability with improvements in Shuttle system.

Source: All data were obtained from the manufacturers or NASA.

Reusable Space Launch Systems

Two concepts for reusable space launch systems which could be used in either a manned or unmanned mode are also being promoted. Both are still in the conceptual stage, and the sponsors have not yet found financing.

The first is called Space Van and is being offered by a company called Transpace Inc. (not to be confused with Transpace Carriers Inc. which is proposing to commercialize the Delta), headed by Len Cormier of Washington, D.C. [2] Space Van could be used in an unmanned "cargo" mode or a manned "orbiter" mode. In the former

[2] The Amazing Private Mini-Shuttle. Space Digest, August 1982, pp. 80–81. Proposed Space Van Wants to Challenge Shuttle for Small Payloads. Satellite Week, October 19, 1981, p. 5. Information also obtained directly from Transpace Inc.

type of mission, the vehicle would operate as a reusable booster with an expendable space stage. In the latter, it would be similar to the Space Shuttle. In both cases, it would be launched from a 747 aircraft, and use Pratt & Whitney RL-10 cryogenic engines. In the cargo mode, a payload of 6,600 pounds could be placed into a 280 mile orbit. Payloads of 1,760 pounds could be placed in geosynchronous orbit, unless low-orbit refueling was used, in which case 6,600 pounds could be placed there. According to its promoters, it might reduce costs to one-fifth that of the Shuttle.

The second concept is for a reusable manned or unmanned launch vehicle called Phoenix. Promoted by Pacific American Launch Systems, Inc., Phoenix would be very versatile according to its creator, Gary Hudson of Redwood City, Calif., and could be used for missions to low Earth orbit, geosynchronous orbit, or even to the Moon. [3] Phoenix would be a single stage vehicle using high efficiency, liquid fueled engines (liquid oxygen, hydrogen, and propane) and would be able to place 5,000-10,000 pounds into GEO without requiring an upper stage. According to Hudson, the Phoenix will be considerably less expensive than the Space Shuttle to launch ($50 million for use of an entire Phoenix vehicle in 1986, compared to an expected $70 million for an entire Space Shuttle flight—actual prices for use of either will depend on the size and weight of the payload).

In-Orbit Space Facilities

Several companies have set forth plans for developing space facilities as cooperative efforts with NASA.

Fairchild Industries of Germantown, Md. signed a memorandum of understanding (MOU) with NASA in September 1982 initiating discussion for the proposed development of a mini space platform called Leasecraft. [4] The facility could be left in space for indefinite periods of time (the Shuttle is currently designed for orbital stay times of two weeks or less), and be tended by the Shuttle on subsequent missions. Leasecraft would provide power, stabilization, communications, and orbital adjustment capabilities for various payloads, and would be based on the Multimission Modular Spacecraft designed for NASA by Fairchild and used already for the Solar Maximum Mission and Landsat 4. Under the MOU, NASA and Fairchild will study Leasecraft with the goal of having it available in orbit by 1986. Fairchild would be responsible for leasing space to government and industry users. Among the payloads expected to require such a facility are materials processing and biological processing plants, and astronomical observatories. NASA would launch Leasecraft for Fairchild in exchange for free use of the platform for certain periods.

A second proposal is by a Houston based company, Space Industries. One of the founders of the company is retired NASA spacecraft designer Maxime Faget who was instrumental in designing

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[3] Percheron Designer Works Toward Launcher for LEO, GEO, and Moon. Aerospace Daily, Feb. 18, 1983, pp. 283-84. Pacific American Launch Systems Unveils New Rocket Design. Satellite Week, February 21, 1983, pp. 4-5.

[4] Potential of Mini Space Platform to be Studied. NASA Press Release 82-141, September 28, 1982.

both Apollo and Space Shuttle. Space Industries signed an MOU with NASA in late 1982 to study the private development of portions of a space station.

Architects Equities Inc. (Champaign, Ill.), has proposed a computer-aided space factory to be operated in the Shuttle by remote control from the ground or with preprogramed robots. The proposal was in response to NASA's request for proposals on space station studies, but did not meet the criteria for actually submitting a bid since it did not meet all mission requirements and the company is not adequately staffed. NASA is reportedly interested in the idea, however. [5]

Ball Aerospace Systems is considering the construction of a facility in which to carry payloads in the Shuttle cargo bay, and signed a memorandum of understanding with NASA in September 1982 to work on development of a joint endeavor agreement. [6]

In 1982, NASA signed a joint endeavor agreement with GTI Corp. for development of a furnace for metallurgical research which would have been mounted in the Shuttle payload bay. After 1 year and an expenditure of approximately $600,000 of its own money, GTI terminated the joint endeavor agreement in the spring of 1983 because it saw no market for the device at this time, and because NASA had not developed the carrier device needed to mount the furnace in the payload bay (construction of the furnace could not proceed without knowledge of that interface). [7]

Materials Processing in Space

Among the areas in which NASA expects substantial commercial activity in the next several years is materials processing in space (MPS). This field includes processes which benefit from the lack of gravity in space, such as electrophoresis (in which biological products are separated from their solution by passing an electric current through the fluid), the growth of more perfect crystals (for use in electronic chips, for example), and the creation of new metal alloys.

NASA experimented with MPS during the Apollo and Skylab programs, although the total amount of time spent on such activities during those programs was only about 8 hours. NASA's joint endeavor program is one method for assisting private industry to perform MPS experiments. Only three joint endeavor agreements have been signed for MPS, however, and one of these has subsequently been terminated. The first, with McDonnell Douglas and Ortho Pharmaceuticals (a division of Johnson and Johnson), concerns electrophoresis, and an experimental device has been flown on two of the six Shuttle missions to date. Three more flights are planned in the series, after which McDonnell Douglas/Ortho may proceed to space factory production. The second joint endeavor was the one with GTI for an MPS furnace discussed previously, while the third is with Microgravity Research Associates, signed in April

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[5] Aerospace Daily, August 17, 1982: 263.

[6] Telephone conversation with Ball Aerospace representative, April 1983.

[7] Joint Agreement Signed for Materials Processing Device on Shuttle. NASA Press Release 82-10. January 28, 1982. NASA and GTI Conclude Joint Endeavor Agreement. NASA Press Release 83-23. February 24, 1983. Lack Of MPS Market Hits Shuttle Furnace Agreement. Aerospace Daily, January 27, 1983, pp. 149-150.

1983, for development of a process for making semiconductor materials.

In addition to the joint endeavor agreements, NASA has also signed a technical exchange agreement with John Deere and Co. to study the effects of microgravity on iron alloys. The agreement, signed between NASA's Marshall Space Flight Center and Deere in July 1981, provides for Deere to use NASA's low-gravity facilities (such as drop tubes and sounding rockets) to conduct research which might lead to future experiments aboard the Space Shuttle. Data is exchanged between the two parties in return for Deere's access to the NASA facilities. Technical exchange agreements have also been signed with Honeywell, Inco, and Dupont,

Other companies reportedly pursuing work related to MPS include: Battelle Columbus Labs, Union Carbide, TRW, A.E. Staley Manufacturing, Beckman Instruments, EG&G, Robert Shaw Associates, Northrop, Terra Mar, Parker-Hannifin Corp., Eli Lilly, and Johnson Matthey, Inc. [8]

Space Shuttle

Several proposals have been made in connection with commercial opportunities associated with the Shuttle. Two of these involve private companies building payload processing facilities near Kennedy Space Center (KSC). NASA is currently in charge of payload processing, but its facilities are overworked. In 1983, Astrotech International announced plans to build a payload processing facility near KSC, and through an exchange of letters made arrangements with NASA to ensure that payloads processed there would meet NASA standards. Hughes Aircraft is also actively considering a payload processing facility near KSC in conjunction with a satellite assembly plant there.

A different type of Shuttle-related proposal was received by NASA in 1982 from SpaceTran Inc., a Princeton, N.J. based firm. SpaceTran offered to purchase a fifth Shuttle orbiter for NASA in exchange for exclusive marketing rights to commercial and foreign users of the Shuttle system. The proposal is undergoing negotiation at the present time and details of changes that have been requested by NASA have not been made public. SpaceTran, which is partially owned by Prudential Insurance Co., is currently in a transition phase following the purchase of 20 percent of the company by Federal Express in early 1983.

Remote Sensing

As noted earlier, no formal proposals have been made for commercializing the civil land and weather remote sensing satellite programs, although the Reagan administration announced plans for such a transfer of operations to the private sector in March 1983.

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[8] These companies have been identified in the following manner: Battelle—telephone conversation with company representative, April 1983; Union Carbide—Aerospace Daily, January 6, 1983, p. 30; TRW, Staley, Beckman, EG&G, Robert Shaw Assoc., Northup, Terra Mar, and Parker-Hannifan—identified by Robert Sharples of TRW as participants in a TRW-sponsored workshop in October 1982 for companies pursuing MPS work in a telephone conversation, April 1983; Eli Lilly and John Matthey—Aerospace Daily, April 22, 1983, p. 309.

In 1982, NOAA, which currently operates these systems, issued a request for information to companies interested in potential operation of the systems and several companies responded. Only one, Comsat, presented a plan for operating both the space and ground segments of the land and weather satellite systems. Comsat's response included possible terms that it might make in a formal proposal to the Government, which included purchase of the existing system for $250–$350 million, plus a guaranteed Government data purchase of approximately $300 million per year for 15 years. Other companies (including Hughes, RCA, General Electric, Control Data Corp.) indicated interest in parts of the Landsat ground segment, but not the satellites themselves.

One company, American Science and Technology (AS&T), has proposed constructing its own remote sensing satellites for launch using the Conestoga launch vehicle. Space Services, Inc., developers of the Conestoga, is a majority stockholder in AS&T.

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THE NEXT 25 YEARS: INDUSTRIALIZATION OF SPACE

- RATIONALE FOR PLANNING -

Jesco von Puttkamer*
Advanced Programs
Office of Space Flight
National Aeronautics and Space Administration
Washington, D.C.

1. Humanizing Space

Dreams about mankind emigrating into space are as old as science fiction. Concepts of permanently occupied and self-sufficient extraterrestrial outposts, bases, habitats, and colonies for settling space have long been envisioned in Earth orbits, on the Moon and on other celestial bodies such as Mars or larger asteroids. More recently, serious writers have suggested that such goals are possible in reality within the foreseeable future, e.g., O'Neill in 1974 (Reference 1). Results from recent NASA studies are generally in support of this work (Reference 2). Some of these projections have included the suggestion that space colonies would be the answer to the "population explosion" on Earth.

Should our next major goal in space, then, be to

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*) Program Manager, Space Industrialization and Integrated Long-Range Planning Studies, NASA - Office of Space Flight.

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Reproduced from Von Puttkamer, Jesco. The Next 25 years: industrialization of space. Washington, U.S. National Aeronautics and Space Administration. [Available from NTIS] [NASA-TM-79360] 1976. 29 p.

establish a colony in space for - say - 10,000 people as proposed by recent studies?

The industrially advanced nations are no longer threatened by overpopulation as are many developing nations. Thus, by not answering a demographic or social need for that part of the world that would have to underwrite the effort, space colonization per se is unable to contribute to a lessening of population pressures in the relevant future.

While space colonization as initial objective and dominant program thrust is clearly not the answer, mankind's expansion into space will be unavoidable in the long run for sheer survival. There can be little doubt that permanent settlements in space will be in mankind's future, and it is one of our most important obligations to future generations to keep these and other growth options open at this time where we are but at the threshold of new frontiers. As the uncertainty about these new frontiers and the possibility of future crisis conditions rise, "safety" lies in maximizing the option potential open to future mankind, to avoid foreseeable and reduce unforeseeable problems.

At the same time, planning of the next steps must be responsive to mankind's near-term needs and wants, while

building a solid foundation of ethical responsibility and technological capability from which an open, choiceful long-term future (or futures) becomes accessible. That alone will provide validity to the Space Program.

In planning the long-range space program based on essentially utilitarian aspects of the near-term without losing sight of the more humanistically significant long-term, and to forecast associated technology requirements, a planning methodology was developed which has recourse to a combination of two basic modes of planning (FIG. 1), extrapolative and normative (Reference 3). In the extrapolative view, responding to the "Push", alternative futures are projected on the basis of past and current trends and tendencies. In the normative view, establishing a "Pull", some ideal state in the far future is envisioned or postulated, and policies and decisions are directed toward its attainment. While the extrapolative view is strictly rational, "cold", and without value statement, the normative planning is truly idealistic, by basing its futures on human values and aspirations, and it would therefore require a value consensus ("Whose norm?"). By not limiting the norms under investigation and keeping all those future options open that appear to be supported

INTEGRATED LONG-RANGE PROGRAM PLANNING

TWO BASIC MODES

EXTRAPOLATIVE VIEW ("PUSH")

- PROJECTS ALTERNATIVE FUTURES ON BASIS OF PAST AND PRESENT TRENDS
- BASES POLICY GUIDANCE ACCORDINGLY
- MAY MISJUDGE CURRENT TREND(S)
- OFTEN FAILS TO SEE THAT SHORT TERM ACTIONS LEAD TO LONG TERM CONSEQUENCES THAT MAY BE UNANTICIPATED AND UNDESIRABLE
- IS ESSENTIALLY VALUELESS, BUT CAN MODIFY TREND LINE IF FUTURE CONTEXT CHANGES

NORMATIVE VIEW ("PULL")

- ENVISIONS IDEAL STATE IN FAR FUTURE AND DIRECTS POLICY & DECISION TOWARD ITS ATTAINMENT
- DEVELOPS FUTURE(S) BASED ON HUMAN VALUES AND ASPIRATIONS
- "FEEDS" FUTURE IMAGE BACK TO PRESENT PERCEPTION OF REALITY AND FACILITATES VALUE CONSCIOUS PLANNING (TIME REVERSAL OF CAUSALITY)
- REQUIRES VALUE CONSENSUS ("Whose norm is to be used?")

REALISTIC APPROACH

- COMBINATION OF BOTH MODES
- PROJECT FORWARD FROM PRESENT WITH EXTRAPOLATION ADJUSTED OVER TIME
- FEED BACK FROM IDEAL FUTURE, RELYING ON EXTRAPOLATIVE GROUNDINGS
- IN PRACTICE: DEVELOP "STEPPING STONES" (INCREMENTS) TO THE FUTURE WHICH ALLOW
  - ASSESSMENT OF BOTH THEIR "BEFORE" AND "AFTER" IN NORMAL AND TIME-REVERSED CAUSALITY.
  - AD HOC ADJUSTMENT OF TREND LINE IN RESPONSE TO NORMATIVE CONTEXT AND EVOLUTIONARY TRENDS.

ORIGINAL PAGE IS OF POOR QUALITY

FIG. 1

by some consensus at present, the problem of deciding whose norm should be baselined can be avoided. A combination of both modes can then yield a more realistic approach to integrated long-range planning by tieing time-reversed vectors of the future to extrapolated, trend-oriented vectors of the quasi-present in a "tree of relevance". By defining development plateaus, common stepping stones can be identified. The "Push/Pull" planning approach, for the first time, appears to offer a useful relationship between utilitarian and humanistic goals of space flight (FIG. 2.)

In thus aiming at long-range goals of humanizing space through colonization, Space Industrialization must first generate an open world that would - through its "re-started" growth processes - make space colonization tenable, supportable and practical. Once established in space, permanent settlements will tap the energy and resources of space, thus easing the mounting human pressure on Earth's dwindling resources, helping remove much industrial activity from the fragile biosphere of Earth, and providing new "frontier" challenge and new worlds for humankind.

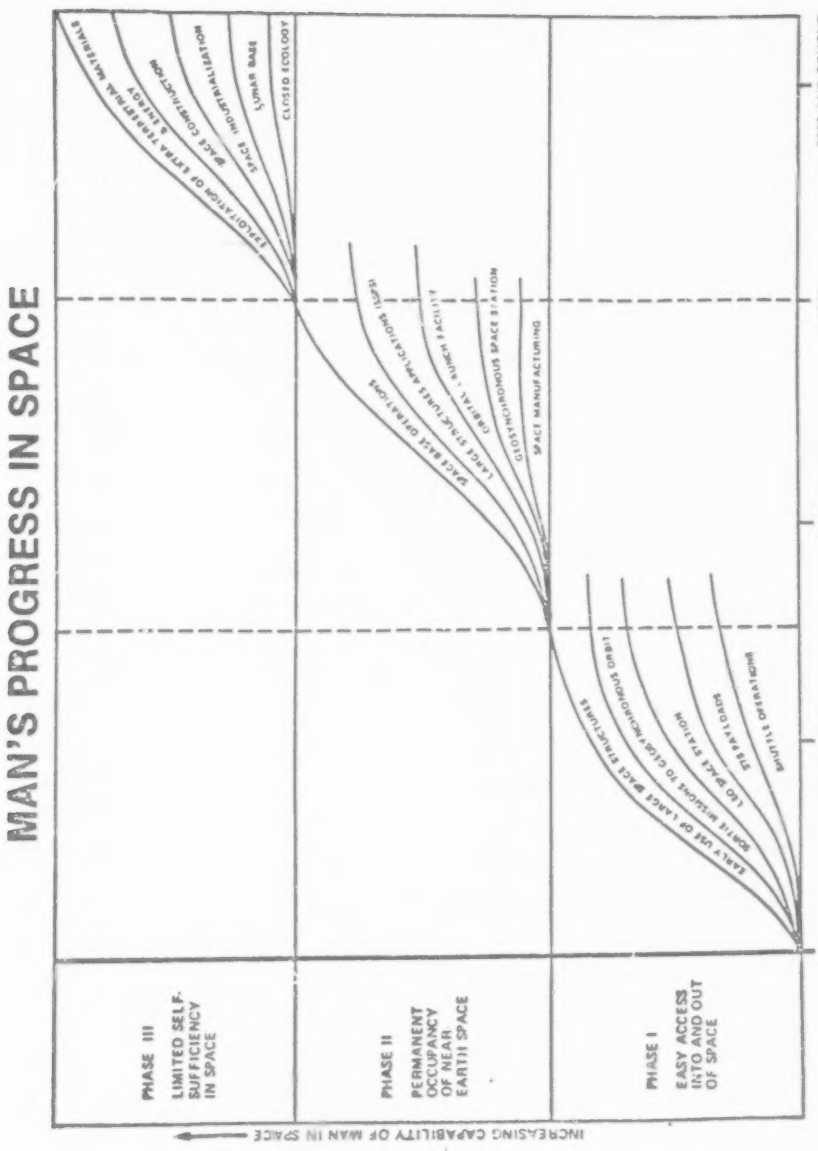
MAN'S PROGRESS IN SPACE
PHASE III
LIMITED SELF-SUFFICIENCY IN SPACE
PHASE II
PERMANENT OCCUPANCY OF NEAR EARTH SPACE
PHASE I
EASY ACCESS INTO AND OUT OF SPACE
INCREASING CAPABILITY OF MAN IN SPACE
1980
1985
1990
1995
2000 AND BEYOND
EARLY USE OF LARGE SPACE STRUCTURES
BOOST MISSIONS TO GEOSYNCHRONOUS ORBIT
LEO SPACE STATION
STS SERVICING
BUILT-UP OPERATIONS
SPACE BASE OPERATIONS
LARGE STRUCTURES APPLICATIONS (ERPS)
ORBITAL TRANSFER VEHICLE
GEOSYNCHRONOUS SPACE STATION
SPACE MANUFACTURING
CLOSED ECOLOGY
LUNAR BASE
SPACE INDUSTRIALIZATION
SPACE CONSTRUCTION
EXPLOITATION OF EXTRA TERRESTRIAL MATERIALS
NASA HQ M7E76 1886(1) 1 1 78

FIG. 2

2. Opening the Closed World

In our present world, both the industrialized and industrializing countries are facing monumental problems. But even more alarming is the dilemma of the nonindustrialized, undereducated, undernourished and undercapitalized nations. Rapidly approaching or already faced with excess population levels, they must undergo social changes at a considerably higher rate than all other countries in history. Their combined growth, based on current rate, will result in well over a billion new people in the next 20-25 years. Extrapolations of this type have led concerned people to seriously consider the Unspeakable, - namely, the imposing of "limits to growth".

There are no longer empty continents with lush vegetations into which excess populations could migrate. Space colonization, as stated before, is not (yet) an answer. Population control is an important nearer-term response, but the inertia-like time lag between birth-rate decline and slowdown in population growth and population stabilization will be many decades (typically 100 years to level off assuming the net reproduction rate reduced to 1.0 by 2025) during which population will continue to grow vigorously (to 10-12 billion at level-off point). Higher

productivity through industry, generation of more capital in the undercapitalized world, and creation of new values and jobs will have to go hand-in-hand with population control to bring the standard-of-living - and the natural acceptance of lower birth rates - of the "developed", highly industrialized countries to both the developing but raw-material-rich and the developing and raw-material-poor nations, in terms of gross national product (GNP), per capita income, energy, food and material consumption, and population index (Reference 4).

3. Goals of Space Industrialization

The intensification and expansion of Earth-based industrialization to support such a global-wide standard-of-living increase at the population levels predicted for the next 30-40 years (requiring an increase of industrialization above current levels by an estimated factor of 35-40) has given cause for serious concern of energy and raw materials availability as well as environmental burden due to waste products, waste heat, and pollutants, supporting the simple fact that in a limited world - as in a shrinking droplet of water - growth is limited. For humans living in such a no-growth world, there will be only one choice: to organize scarcity. As a result, their

future will quite likely be characterized by scarcities, deficiencies, shortfalls, defensive Earth resources policies, regression to intensified battle for survival, and new fragmentation of mankind. Thus, in a closed world, a fourth complex of problems joins the dilemma of population increase vs. living standard vs. environment: social strife and warfare.

For the opening of the essentially two-dimensional world with its "flat", closed surface limited in resources, energy and human real estate, to the three-dimensional environment of space to be effective, space must contribute to removing the limits to growth by not only generating new products and services but, in fact, by "shunting" energy- and pollution-intensive components of Earth industry into space where both energy and waste reservoir are plentiful (Reference 5). In addition to organizing scarcity to preserve, recycle and substitute for limited resources, a second choice becomes viable: the creation of wealth for all mankind without detrimental environmental impact.

Foremost among the needs faced by the large majority of mankind (over 70%) are industrial development and

diversification, unemployment, population growth rate, agricultural development and food supply, rural and urban development, and health and education. For the industrialized nations, additional concerns pertain to energy shortage and independence, raw materials depletion, environmental burden, and inflation/recession. Clearly, to be morally supportable, Space Industrialization must contribute to the solution of these problems, both on a national (U.S.) level and - eventually - on a global scale.

The goals of NASA's Space Industrialization program, thus, include making a major contribution to increased productivity on Earth without taxing the environment, generating new values through extraterrestrial productivity, and providing new growth options for the future which would include permanent settlement of space and long-range colonization and exploration projects.

The task of balancing the needs of mankind with the requirements of maintaining the Earth's biosphere through the industrialization of space will - by necessity - be approached through a step-by-step evolution.

4. Stepping Stones

Space Industrialization, by developing the permanent and productive use of environments beyond Earth, must be based on the economic principles of cost effectiveness and commercial competition. This in itself presupposes the introduction of "stepping stones" to the overarching concept of Space Industrialization in order to facilitate the transfer of the investment capitalization from the public (Federal Government) sector to private industry. Since capital cost and interest rates are significantly affected, as is inflation, by the length of time and the extent to which investment capital is tied down unproductively in development (requiring discounting), return (pay-back) times on investment and the time until breakeven must be minimized. In addition, the higher the confidence level that influential features of the future Space Industrialization systems/programs can be maintained within acceptable tolerance bands, the lower the risk to the investor. Both arguments stipulate a stepping-stones approach that provides "manageable" increments within the "Push/Pull" force field of the overarching (long-range) concept.

In addition to providing reduced investment steps and shorter pay-back times, the pre-planned plateau approach (Reference 3) or "technique of small steps" allows

- Goal-oriented program planning and management,
- Built-in "holds" for successive re-evaluation of subsequent goals and objectives,
- Built-in "holds" for introduction of new technologies, both improvements and replacements/breakthroughs, and
- Better assimilation of space progress in Earth's culture and concurrent consolidation of technological progress with (slower) humanistic/cultural development.

By expanding the biosphere to include the space dimension, access is obtained to functionally infinite materials and practically infinite energy supplies. Some of the attributes and resources of space that are of relevance are listed in TABLE 1.

Based on this wealth of potentially attractive features, the guiding principles of Space Industrialization must therefore be to (a) exploit the availability of virtually unlimited energy, (b) exploit the excellent transmission characteristics for energy and information, (c) exploit the large geometrical coverage, and (d) exploit the benign environment (except for radiation belts). A summary of candidate activities is given on FIGs. 3a and 3b (Reference 4).

- Easy gravity control from ambient zero-g (or micro-g) to any desired rotationally induced multi-g-level
- Absence of atmosphere -
  - unhampered viewing of space for astronomy, astrophysics, etc.
  - perfect vacuum and freedom from seismic, acoustic, and convection disturbances
- Comprehensive overview of Earth surface and atmosphere
- Isolation from Earth's biosphere (for hazardous processes)
- Freely available light, heat, and power
- Infinite natural reservoir for
  - unlimited disposal of waste products
  - safe storage of radioactive products
- Super-cold temperatures (heat sink)
- Large, three-dimensional volumes (storage, structures)
- Variety of non-diffuse (directed) radiation
- Magnetic field
- Extraterrestrial raw materials

USEFUL ATTRIBUTES OF SPACE

TABLE 1

SPACE INDUSTRIALIZATION
EXAMPLES OF OPPORTUNITIES - 1

INFORMATION TRANSMISSION FOR PUBLIC SERVICES

- COMMUNICATION: Person-to-person, Voting/polling, etc.
- DATA TRANSMISSION: Electronic mail, Package tracking, Surveillance
- NAVIGATION/TRAFFIC CONTROL: Personal, Air Traffic, Ships
- INFORMATION STORAGE: For Recall from Earth or Space, Computer in Space.
- PUBLIC INFORMATION SERVICE: Education, Cultural/entertainment programs.

DATA ACQUISITION/TRANSMISSION

- METEOROLOGY: Accurate Weather Predictions
- PROBING OF ATMOSPHERIC LAYERS: Ozone layer, Ionosphere
- LAND MONITORING: Resources, Fault zones, Earthquake areas, coasts.
- OCEAN MONITORING: Currents, Wave conditions, Icebergs, Marine life
- COLLECTION/TRANSMISSION FROM SURFACE BUOYS AND BALLOONS
- SOLAR ACTIVITY MONITORING: Flare warning, etc.

EARTH-ORIENTED TELEOPERATION AND TELEMONITORING

- LONG PIPELINES AND POWER LINES
- REMOTE INDUSTRIAL FACILITIES: Desert Solar Power Stations, etc.
- REMOTE AGRICULTURAL FACILITIES
- REMOTE HUMAN ACTIVITIES: Expeditions, Search/Rescue, etc.

NUCLEAR WASTE DISPOSAL

- FROM EARTH SURFACE: To long-lifetime orbits or Sun
- FROM VICINITY OF ORBITING INDUSTRIAL FACILITIES

FIG. 3a

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SPACE INDUSTRIALIZATION
EXAMPLES OF OPPORTUNITIES - 2

MANUFACTURING IN LOW EARTH ORBIT

- HIGH-COST LOW-WEIGHT/VOLUME PRODUCTS: from Earth-supplied Materials
- STRUCTURES & STRUCTURAL ELEMENTS FOR SPACE FACILITIES: from Earth- or Moon-supplied Materials

SPACE LIGHT (ILLUMINATION FROM SPACE)

- INDUSTRIAL/AGRICULTURAL OPERATIONS, COMMERCIAL TRAFFIC, URBAN AREAS
- FOOD PRODUCTION: Plankton growth, etc.
- WEATHER MODIFICATION: Crop damage prevention.

SPACE MICROWAVE POWER (ENERGY FROM SPACE)

- LONG-DISTANCE RELAY OF POWER FROM SOURCE TO USER CENTER
- SPACE-GENERATED POWER TO TERRESTRIAL USER CENTER
- SPACE-GENERATED POWER TO SPACE INDUSTRIAL FACILITIES

LUNAR INDUSTRIALIZATION

- SUPPLY OF OXYGEN FOR ROCKET PROPULSION/LIFE SUPPORT: Transportation
- STRUCTURAL & MANUFACTURED GOODS TO ORBITING FACILITIES
- PRIMARY COMMODITIES & MANUFACTURED GOODS TO EARTH

HUMAN ACTIVITIES

- MEDICAL/THERAPEUTIC SERVICES/OPPORTUNITIES: Curative & Alleviative
- RECREATION: Space Tourism Facilities

SOLAR SYSTEM INDUSTRIALIZATION

- MARS: STAGING & SUPPLY BASE FOR ASTEROIDAL UTILIZATION
- ASTEROIDAL METALS FOR EARTH
- HELIOCENTRIC EXPLORATION

FIG. 3b

NASA HQ MT/G 408/III (1)
R 74 /b

As a logical consequence, Space Industrialization introduces several new and interlinked commonality features that will become characteristic of future space activities, viz.,

- Large structures in space
- Complex systems in space
- Long flight durations
- Manned orbital service and maintenance.

While the long-range motivation of Space Industrialization, the "Pull", is physical and humanistic expansion - and thus survival - of mankind, the nearer-term goals of Space Industrialization are three-fold: provide energy from space, provide space-derived products or goods that are salable and profitable, and furnish space-derived services for which agencies, industries and the public are willing to pay.

5. Applications

ENERGY. The problem of satisfying the energy demand of the industrialized world, as currently perceived, will reach near-critical proportions over the next 25 years. The electric power capacity of the U.S. alone is expected

to triple (from 500 GW to 1500 GW) before 2000, requiring investments on the order of a trillion dollars, and to continue to grow. There is no obvious single source to supply this demand growth: Oil, gas and conventional nuclear power generation uses depleting, irreplaceable resources (i.e., living off "capital"); nuclear fusion development is uncertain at this time, and its costs are unknown; solar-terrestrial power (photovoltaic, thermal, wind, etc.) appears to be penalized by high cost and the problem of energy storage.

Without Space Industrialization, prospects for power sources by 2000 appear to be limited to coal, using existing technology, and breeder reactors, requiring development*) For both options, there exist problems of environmental burden and potentially high cost. An additional problem, pointed out by K. Ehricke, is the high cost of electrical power transmission, requiring presently more than 400,000 miles of high-voltage lines in the U.S., with 11,000 square miles of right-of-way real estate.

The potential benefits of Space Industrialization to the energy problem can be three-fold:

*) First breeder reactor is expected to come on line about 1992-93, with doubling time (for fuel) of 30-60 years, improving to 20 years thereafter.

- by providing technology useful for generating and/or transmitting power on the ground,
- by providing RF power reflectors in space for passively relaying electrical power from ground power plants to ground users, and
- by generating power in space for transmission to the ground.

Replacing the current 64 kV transmission lines with higher-voltage cables is one answer to the power transmission problem. Switching from AC to DC power may be a better, more economic solution, according to Rockwell International, but it would require high-voltage AC/DC rectifiers and inverters. Such devices use terrestrially produced silicon crystals of 4-7 cm diameter (where size determines maximum power level). By producing these crystals in space, a choice of sizes up to 15 cm could be provided, allowing a reduction in number of crystals needed for a given power level to 7% of the number of 4 cm crystals. Potential cost savings due to reduced construction requirements are estimated at $76.5 billion by 2000 (assuming 1000 GW generating capacity).

Even more significant may be the impact of "clean" power generated from solar energy from space. For solar-terrestrial (ground) collectors, availability of the Sun is roughly 17% of the time in Arizona and 6% average

nation-wide (Reference 6). By relocating the solar collector array from the day/night cycle and atmospheric environment of the ground to a suitable Earth orbit, solar radiation would be available over 99% of the time, limited only by occasional passes through Earth's shadow. This means that a power collector in space (11,800 kWh/m^2 per year) would intercept almost 6 times as much as one in Arizona (2000 kWh/m^2 annually), and almost 17 times as much as the U.S. ground average (700 kWh/m^2-year).

After collection of the energy in geosynchronous orbit, electricity would be generated in space through one of a number of possible conversion techniques, listed below. For subsequent transmission to Earth (or to a space-based industrial facility complex), the DC electricity would be converted to microwave RF through amplitrons (vacuum-tube type amplifiers such as klystrons are unnecessary in the vacuum of space), and beamed to a receiver antenna (rectenna) on Earth. Atmospheric transmission losses for microwave energy at the 2.45 GHz level would amount to no more than 2-8%. The entire DC-to-DC transmission chain itself is expected to achieve a level of about 58% efficiency (Reference 7).

Conversion techniques, presently under investigation by NASA and its contractors, may be photovoltaic (light energy) or solar-thermal (heat energy). The latter category includes thermionic, Brayton-cycle, thermionic Brayton-cycle, and Rankine-cycle systems. The former uses vast arrays of solar cells (silicon). Overall efficiencies of solar power satellites (from interception to AC ground power busbar) are estimated at 4-8% for photovoltaic, 6-17% for thermal systems.

To make the solar power satellite system economically viable, a considerable amount of power must be delivered, requiring very large collector arrays. For a ground power output of 10 GW, a photovoltaic array would cover an area of 129 km^2 and have a mass of 34,000 metric tons. Its development costs are estimated at $50 billion, its energy production cost at 27 mils/kWh. For comparison, a Brayton-cycle thermal satellite system would require only 70 km^2 of size, but 151,000 tons of mass, $59 billion of development cost, and 50 mils/kWh of energy production cost (Reference 7).

If sold "at cost" of $.027 per kilowatt-hour, the power output of a photovoltaic satellite would yield an annual revenue of $2 billion, i.e., a square kilometer of space would return more than $15,500,000 each year.

PRODUCTS (Goods and Services). Exploitation of the unique environment of space for processing of commercial inorganic and biological/pharmaceutical materials as well as manufacturing of new products designed to enhance productivity on Earth are expected to develop very high industrial potential. Not only would such activities affect world trade and lead to lower costs, thus benefitting national and global economy, but they would also be of importance to human health by benefitting disease prevention and more effective treatment.

At present, we know of five basic types of industrial processes that require a zero-g environment for improved material quality, more efficient material utilization, commercially significant production volume, and lower cost:

1. Crystal growth, including growth from a melt, growth in solution, and growth from the vapor phase.
2. Purification/separation.
3. Mixing.
4. Solidifications.
5. Processes in fluids.

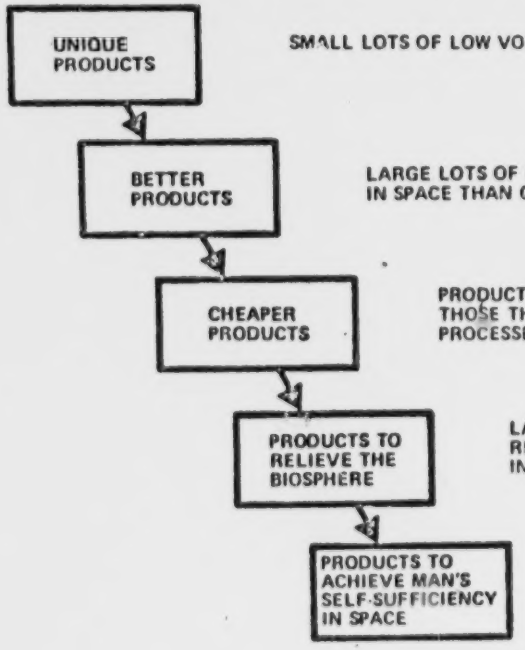
Other processes require high vacuum, such as vapor deposition techniques.

The possible evolution of Space Processing and Manufacturing of Goods along plateaus or stepping stones of immediate and contemporary benefit toward far-future goals of Space Colonization are highlighted in FIG. 4. Again, the stepping-stone approach would allow sponsorship by the Government during the high-risk concept formulation phase, with subsequent shift of emphasis to private/commercial investment. The detailed plans for government/industry interaction have yet to be constructed and are presently under early study; however, they can be expected to vary with the product or service produced.

Top candidates on NASA's list of inorganic commercial products made in space are semiconductor materials such as silicon or gallium-arsenide ribbons for wafers and chips, vapor-deposited solar cells, and niobate crystals for lasers and memories. For example (Reference 8), producing crystal chips in the gravity field on Earth from cylindrical boules yields 37% of useable wafers which in turn are processed into 21% of tiny electronic chips for integrated circuit (IC) substrates, resulting in an overall yield of 8%. For comparison, processing of the semiconductor material in ze. g in ribbon-form would bypass the wafer stage and lead directly to chips, with an overall

EVOLUTION OF SPACE INDUSTRIALIZATION

EXAMPLE: SPACE PROCESSING & MANUFACTURING OF GOODS



SMALL LOTS OF LOW VOLUME/HIGH VALUE GOODS THAT CAN ONLY BE MADE IN SPACE

LARGE LOTS OF HIGH VALUE GOODS THAT CAN BETTER BE MADE IN SPACE THAN ON EARTH

PRODUCTS THAT ARE CHEAPER MADE IN SPACE, SUCH AS THOSE THAT RESULT AS BY PRODUCTS FROM PRIMARY PROCESSES

LARGE VOLUME/LOWER VALUE GOODS REQUIRING ENERGY- AND POLLUTION-INTENSIVE PRODUCTION

SPACE COLONIZATION

FIG. 4

NASA HQ MT76-1182 (1)
11-10-75

yield of 35%. There would thus be an improvement, i.e., profit margin, of 4½ to 1 over ground processed chips.

According to Western Electric Manufacturers Association (WEMA), the market for ICs in the free world was on the order of $5 billion in 1975, with $6 billion predicted for 1977. Extrapolation leads to an annual average of $19 billion between 1985 and 1989. The share of silicon, as raw material, in this market is estimated at about 10%.

Among the space-manufactured metals of interest are materials for high-strength permanent magnets, turbine blades, and X-ray targets.

Even more important will be separation and culture-growth processes of biological products such as pancreatic cells (insulin), pituitory cells, edothelial cells (macrophages), bone marrow, blood cells (lymphocytes, granulocytes), sperm cells (control of sex in farm animals), and enzymes. Space-processed biologicals include the enzyme urokinase with the potential of preventing up to 50,000 deaths per year in the U.S. due to thromboembolisms (blood clots), and erythropoietin for the treatment of kidney failure and anemia. In the U.S. alone, the annual requirements for urokinase are 500,000 doses at an Earth-produced cost of $2.5 billion. If produced from space-

enriched material, the cost would amount to only $400 million (Reference 9).

Similar considerations apply to space-processed lymphocytes (for prevention of organ transplant rejection) and macrophages (for early detection of immunological reaction).

PUBLIC SERVICES. Basic concepts of making space useful and directly relevant in the everyday life of large numbers of ordinary citizens involve the placing of very large satellites and antenna structures into orbit.

In a reversal of a previous space flight principle which required that spacecraft be kept as simple, light-weight and reliable as possible by relegating functions associated with complexity and weight to ground stations, the achievement of easy access to and from space and permanent occupancy of space by people will permit us to develop and operate large and complex satellites.

NASA studies indicate that in many applications of information transfer minimum total system cost might be achieved by deliberately making satellites large and highly capable, accepting their expense in order to allow

the user equipment to be tiny, highly portable, and inexpensive. Because of the vantage point of geosynchronous altitude, millions of Earth-based users can be serviced by one or only a few satellites, and the cost of even very large and capable satellites and antennas could be expected to be less than that of the terminals, resulting in minimum total cost while simultaneously performing functions of unprecedented system utility not possible with simpler and smaller satellites. By using people in space for assembling, maintaining and servicing advanced systems of this type, these satellites can reach very large size. Due to the weightlessness of space, however, the erection and assembly of large antennas and reflector structures will not be subject to the constraints of weight deflections. Typical active multi-beam antennas for RF and microwave output identified to date would measure 200 to 600 feet in diameter and operate at power levels of 20-150 kW. Passive space reflectors for beaming light to Earth or relaying energy can reach diameters of 1000 to 3000 feet (Reference 10). Space power collectors may measure miles in length and width, as stated before.

The new, almost unlimited opportunities offered by space communications using these advanced systems have the potential to answer many serious needs of mankind in

numerous personal, civic, government, industrial, and international applications in the next 25 years and beyond.

For improved personal communications, for example, a single 200-ft satellite could service 2,500,000 people with two-way voice and data communications, using ground user radio sets no larger than a "Dick Tracy" wristwatch radio. For improving mail communications, a multi-beam satellite with total U.S. coverage may relay up to 30% of U.S. mail electronically (100 billion pieces per year) and accrue cost savings on the order of $1 billion/year. Improved educational opportunities would become available with a large, high-power TV direct broadcast satellite bringing televised programs to mountainous, rural and remote areas of the world. Multi-beam satellites that provide citizens via wrist radio with around-the-clock access to police headquarters, and police with jam-proof communications from any location, will reduce crime rates. Improved public and governmental services could be obtained by using multi-beam satellites for direct and immediate communications to disaster areas as well as direct, instantaneous individual voting and polling. Intrusion detection of ships, personnel and goods across borders and coasts by large RF arrays in space, global communications

with ocean vessels via space-based low-frequency loop antennas, and 24 hr/all-weather monitoring of global air and ocean traffic with a large microwave antenna satellite could improve national security and international air/sea traffic lines (Reference 10).

To achieve these long-range goals in a practicable step-by-step "Push/Pull" development, Space Industrialization would make use of a Space Construction Base (FIG. 5) in the early 80's to (a) develop and demonstrate concept technology, (b) erect, assemble and test large structures in space, and (c) develop the first operational communications systems by transferring complexity from ground to space.

Early NASA studies of a Public Service Platform (PSP) indicate that integrated platform concepts with multiple functions may be superior to non-integrated separate satellites with dedicated antennas. A typical first stepping stone, by 1985, may be a demonstration antenna of about 2400 m^2 area and 7 kW of RF power in a 500 km orbit, with four different voice/data transmission functions. Subsequent growth to a 3-antenna platform with 13 functions (voice/data transmission functions, voice/video/imaging functions, and security/safety detection and control functions) and relocation from low Earth orbit

SPACE CONSTRUCTION BASE
EARLY SYSTEM OBJECTIVES

- CONSTRUCTION RELATED
  - SATELLITE POWER SYSTEM
  - NUCLEAR ENERGY
  - EARTH SERVICES
  - SPACE COSMOLOGICAL R&D
- SPACE MANUFACTURING
  - SPACE PROCESSING
- SUPPORT OBJECTIVES
  - CLUSTER SUPPORT SYSTEM
  - DEPOT
  - MULTIDISCIPLINE SCIENCE LAB
  - SENSOR DEVELOPMENT
  - LIVING AND WORKING IN SPACE

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FIG. 5

to geosynchronous altitude could be achieved as next step in 1986/87 (Reference 11).

6. NASA Studies

The total, overarching concept of Space Industrialization is currently becoming subject of intense study. These efforts, contracted with Rockwell International and Science Applications, Inc. (Reference 12), are primarily a planning activity intended to lay the necessary groundwork for subsequent implementation phases of a Space Industrialization program and the required support programs, including space transportation systems, domiciliary facilities in space, and space assembly/manufacturing facilities. Prime objective of these efforts is to develop an evolutionary Space Industrialization program which leads from Shuttle/Spacelab and early Space Station/Space Construction Base experiments to the permanent, practical and commercial utilization of space.

7. Summary

Space Industrialization has joined science and exploration as a major concept of space activity that introduces new themes of human space flight (FIG. 6).

NEW THEMES FOR MANNED SPACE FLIGHT

- ON-ORBIT EXPERIMENTATION, INSTRUMENT DEVELOPMENT, SERVICING & MAINTENANCE
  - PRODUCTION AND MANAGEMENT OF FOOD AND FORESTRY RESOURCES
  - PREDICTION AND PROTECTION OF THE ENVIRONMENT
  - PROTECTION OF LIFE AND PROPERTY
  - ENERGY AND MINERAL EXPLORATION
  - TRANSFER OF INFORMATION
- SPACE ASSEMBLY, CHECKOUT, EMPLACEMENT, AND SERVICING OF LARGE STRUCTURES
  - SOLAR POWER CONVERSION AND TRANSMISSION
  - TERRESTRIAL POWER RELAY
  - SPACE LIGHT ILLUMINATION
  - RADIO-ASTRONOMY
  - AID TO CIVIL PROBLEMS (OBSERVATIONS. COMMUNICATIONS, SUPPORT SERVICES)
- SCIENTIFIC AND COMMERCIAL UTILIZATION OF SPACE
  - BASIC PHYSICS AND CHEMISTRY
  - MATERIAL SCIENCE
  - COMMERCIAL INORGANIC PROCESSING AND MANUFACTURING
  - PRODUCTION/ISOLATION OF BIOLOGICALS (e.g., BLOOD CELLS, VACCINES, INSECTIDES)
  - EFFECTS OF GRAVITY ON TERRESTRIAL LIFE
  - MAN LIVING AND WORKING IN SPACE
  - PHYSIOLOGY AND DISEASE PROCESSES
- STEPPING STONES FOR FUTURE HUMAN NEEDS AND OBJECTIVES
  - IMPROVEMENT OF TECHNOLOGY/CAPABILITY (TRANSPORTATION, HABITATION, OPERATION)
  - DEVELOPMENT OF CLOSED ECOLOGY SYSTEMS (SPACE-BASED AGRICULTURE, ATMOSPHERES)
  - DEVELOPMENT OF HUMAN PHYSIOLOGICAL ADAPTATION TO SPACE
  - ACCESS TO EXTRATERRESTRIAL RAW MATERIALS AND ENERGY
    - SPACE INDUSTRIALIZATION
    - OCCUPATION AND SETTLEMENT OF THE MOON
    - COLONIES IN SPACE
    - MANNED MARS EXPLORATION
    - HUMAN EXPLORATION OF THE SOLAR SYSTEM
    - INTERSTELLAR FLIGHT

FIG. 6

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In mankind's long-range drive to humanize space and achieve eventual space colonization, the industrialization of space can offer a realistic approach to developing a progressive program to provide permanent, practical and commercial utilization/tools of space through products and services that create - in the long run - new values, jobs, and better quality of life for all mankind.

The planning of such massive space endeavors as space colonization in the far future is quite helpful since it enables us to trace possible pathways of "Push/Pull"-type development through Space Industrialization back to the present. In thus establishing a "relevance tree" (FIG. 7) between far-future "dreams" and near-term realities and "pragmatisms", we are in a better position to identify major stepping stones which are useful to mankind in terms of contemporary benefits (short-term returns) while at the same time being relevant to future growth-type needs. Once these vectors are established, we do not have to be too specific about the actual far-future goals and can leave their selection up to our future generations.

EVOLUTIONARY PATHS TO FAR-FUTURE SPACE ENDEAVORS
(Relevance Tree)

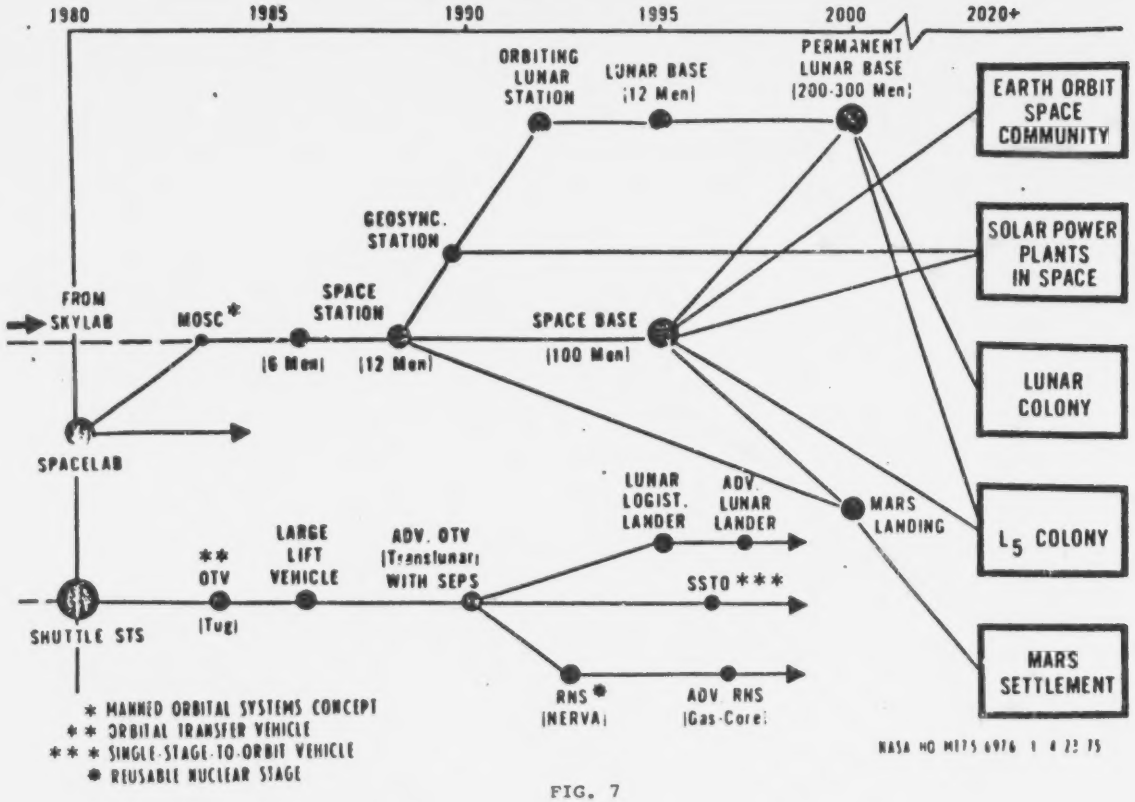

FIG. 7

This approach brings "dreams" into the realm of "strategic" thinking. It allows us to (1) give a larger purpose to our near-term "tactical" and pragmatic activities and thus re-introduce the "dream" in our "Now"-orientation, and (2) improve our ability to avoid dead-end "branches" in our major planning decisions for Space Industrialization.

The merits of Space Industrialization lie in the fact that they encompass all human beings. This is a new fundamental premise, untenable without highly developed industrial foundations. Knowledge, health care, and the satisfaction of other existential and higher needs no longer are privileges of a few but fundamental rights of all. While space colonization, if taken as initial goal and prime objective, would probably "benefit" only a relatively small group of people living in a space colony, Space Industrialization can benefit <u>all</u> people on Earth. Moreover, it would not preclude but in fact validate the option that the industrialization of space may subsequently grow into space colonization as full self-sufficiency in space is reached. By being basically non-elitist, Space Industrialization will thus introduce the true humanization of space.

***

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October 1976

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SPACE INDUSTRIALIZATION STUDY

FINAL REPORT - VOL 1

SPACE INDUSTRIALIZATION
- AN OVERVIEW

APRIL 15, 1978

PREPARED UNDER NASA CONTRACT NAS8-32197

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SCIENCE APPLICATIONS, INC.
2109 W. Clinton Avenue, Suite 800
Huntsville, Alabama 35805 (205) 533-5900

FOREWORD

This $198,962.00 Space Industrialization Study was performed under NASA Contract NAS8-32197 for Marshall Space Flight Center from September 1976 through April 1978. The study was in two parts: Part 1 identified the future opportunities for space industrialization, quantified the potential benefits and developed and analyzed evolutionary program options required to take advantage of these opportunities; Part 2 defined the framework of international governmental, industrial, legal and economic constraints within which space industrialization (SI) must evolve. Step-by-step guidelines to implementation of programs to capitalize on the SI opportunities were formulated using information from Part 1 and Part 2. The study results are documented in four volumes:

1. SPACE INDUSTRIALIZATION - AN OVERVIEW
2. SPACE INDUSTRIALIZATION - OPPORTUNITIES, MARKETS AND PROGRAMS
3. SPACE INDUSTRIALIZATION - WORLD AND DOMESTIC IMPLICATIONS
4. APPENDICES

Part 1 of the study was managed by Dr. Ralph Sklarew and Part 2 by Mr. Gerald W. Driggers. Other key SAI participants were Mr. E. Battison, Mr. D. Davis, Mr. Sam Gibson, Mr. Mark Klan and Mr. Gordon Collyer. A large portion of the work reported here was accomplished by consultants who occupied roles as principal investigators. The key consultants were:

- Mr. Robert Salkeld - System Planning and Programmatics
- Mr. G. Harry Stine - Industrial Planning and Marketing
- Mr. Paul Siegler - Market Assessment and Economic Analysis
- Dr. J. Peter Vajk - World Dynamics and Futures Assessment

A subcontract to Southern Research Institute (SoRI) in Birmingham, Alabama, was managed by Mr. Driggers during Part 1 of the study, prior to his joining SAI. Key participants at SoRI were Mr. S. J. Causey and Mr. R. Monroe.

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- Dr. Carleton S. Coon
- Barbara Marx Hubbard
- Donald Waltz
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- Dr. David Criswell
- James Harford
- William E. Bittle
- J. Frank Coneybear
- Bruce W. Dunbar
- R. G. Woodbridge, III
- Ralph A. Rockow
- Dr. Brian O'Leary
- Paul S. Hans
- Dr. Sven W Englund
- Arthur Dula
- Darryl Branscom
- Rashmi Mayur
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The study was performed under the technical direction of Mr. Rodney Bradford (Part 1) and Mr. Georg von Tiesenhausen (Part 2), Marshall Space Flight Center. Mr. J. von Puttkamer was the program manager for NASA Headquarters, Office of Space Transportation Systems.

Inquiries regarding the study should be addressed to the following:

- Georg von Tiesenhausen
  NASA Marshall Space Flight Center
  Attention: PS01
  Huntsville, AL 35812
  Telephone: (205) 453-2783

- Gerald W. Driggers
  Science Applications, Inc.
  Suite 800
  2109 West Clinton, Avenue
  Huntsville, AL 35805
  Telephone: (205) 533-5900

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1. SUMMARY

Space Industrialization (SI) is the medium by which services, energy and products are returned from space to Earth to provide economic and other pragmatic benefits to mankind. Although this study focuses on the United States as the mechanism for benefit generation and transfer (with an appropriate payback to its industry and citizenry for investing resources and labor), it is the world that benefits. Indeed, the underdeveloped and developing countries are now, and will continue to be, prime beneficiaries from Space Industrialization. It is possible to construct credible scenarios which step these nations into the twentieth century equivalent of the U.S. in less than 100 years, without significant local or global economic or environmental damage. The great power for what is considered "good" in the western world (health, safety, knowledge, creative growth, etc.) afforded by Space Industrialization has been comprehended by a very few, but there is evidence that realization is spreading. It is hoped that this document and this report, in conjunction with the companion report by Rockwell International, will assist in this realization, and help promote early expansion of the beneficial returns on humanity's investment in space.

The SAI study concentrated on the U.S. and what we may gain from the investing of our resources, both public and private, in SI. The future was examined to characterize resource pressures, requirements and supply (population, energy, materials, food); also, the backdrop of probable events, attitudes and trends against which SI will evolve were postulated. The opportunities for space industry that would bring benefits to Earth were compiled and screened against terrestrial alternatives. Most survived, and a population of the survivors were examined to determine if SI would ever be "worth the investment". A cursory market survey was conducted for the selected services and products provided by these initiatives and the results were astounding. Space Industrialization is a billion dollar a year business now; in thirty years it could grow by 100 times that amount or more!

But, space is expensive. Might not the investment outweigh the gain? Programs of SI evolution corresponding to the postulated future scenarios were developed, and the investments compared to the revenues and their associated benefits. The program analysis results brought two observations: SI investments will be good investments and the sooner the investment, the better for all concerned (in terms of the pure mathematics). It was recognized, however, that certain other factors may control the practical rate of progress.

These "other factors" were examined to the extent practical in this study; a great deal remains to be done. The following observations are in order, however, based on this assessment.

(1) Foreign competition is becoming very strong in SI. It is no longer "our" domain and these pressures will increase. This may limit or spur U.S. increased involvement.

(2) The developing and underdeveloped nations of the world may consider the U.S. and SI a threat or a powerful tool for progress depending on how we promote it.

(3) Prospects for economic return to the government (public sector) are excellent, so long term investments should be justifiable. A few billion of dollars invested in the eighties will result in hundreds of billions in tax revenues, millions of jobs created, strong economic growth and good balance of trade impact in twenty years or less.

(4) Although some U.S. industry will resist SI, a strong support base can be built among U.S. private enterprise.

(5) In both domestic and international law there are no legal entanglements which will seriously inhibit SI development, if we develop proper policies and stick to them!

(6) Although many social and political institutions will be affected by SI, the most significant are those institutions governing industry and government relations and those relating the U.S. to the rest of the world. Nothing precludes mutually beneficial arrangements in both of these arenas. Historically, such arrangements have taken several years to evolve.

(7) The most important SI initiatives would appear to have rather high initial investments, and payback periods longer than normal for private investment. A mechanism for reducing initial risk and shortening these payback times is possible and will attract substantial industry support upon initiation.

Thus, in sum, this study has concluded that Space Industrialization exists and substantial and sustained growth is highly desirable. From examination of the SI programs and their characteristics the following recommendations were drawn.

(1) Strong industry involvement in all areas of SI from planning to ultimate operations is necessary to return maximum benefits.

(2) A central group, perhaps under the Administrator of NASA, especially tasked to plan, integrate and advocate SI activities is needed badly. Such a group, located within the government, may indeed be essential if private enterprise can not meet the challenge on its own.

(3) Space Industries will need 25 to 75 KW of raw power in the early-to-mid-eighties, 100 to 500 KW in the latter eighties and 1-10 MW in the early to mid-nineties. A Solar Power Satellite prototype development program to prove technical/economic feasibility and environmental acceptability would have similar milestones and characteristics. Space power needs for products have a similar progression, with the possibility of a three to five year lag in demand relative to other requirements. A space power program designed to integrate and synergize these requirements should be initiated, beginning with development of the 25 KW Power Module currently proposed. The requirements for a concurrent large structures program is implicit to the power program.

(4) The cost of space transportation to low Earth orbit must come down below shuttle projections by a factor of 10 to 100 to really open the products market in the nineties. The Shuttle is the key, but the longer term SI requirements are already apparent. Increases in flexibility and decreases in cost are needed by high orbit operations in the latter eighties for both services and energy initiatives. Propulsion and vehicle programs to meet these needs should be integrated into future transportation planning.

(5) The U.S. (probably through the NASA) should embark on an intensive data gathering and planning effort during FY 79, 80 and 81 in parallel to initiation of early projects such as 25 KW Power Module. This effort would culminate in a carefully coordinated, evolutionary Space Industrialization Plan with domestic and international as well as government and industry segments.

The above recommendations imply only modest budget commitments over the next three years (less than five million per year in studies and planning and less than fifty million per year in hardware commitments). The budget requirements for development and implementation of initiatives with early direct returns (mid to late eighties) plus long lead technology development for the nineties has a funding peak of less than four billion dollars annual. That cost could be shared in various ways between NASA, other government agencies, private industry and international (or foreign) organizations. The space technology peculiar funding requirements are less than two billion of the four billion total.

A great deal of work remains before Space Industrialization enters the main stream of government and industry planning, and a proper public understanding is achieved. A solid information base, a dedicated advocacy group and very hard work are the essential ingredients to accomplishing these objectives. The rewards will be worth the effort, and attaining these goals will turn Space Industrialization into the mechanism for achieving the next plateau of human development.

The remainder of this document provides discussion in greater depth in the tasks of the study as outlined in the Summary. Volumes 2, 3 and 4 of this report contain the in-depth discussion and data.

2. THE TERRESTRIAL BACKGROUND FOR SPACE INDUSTRIALIZATION 1980 - 2010

During the next few decades, space technology (developed for purely scientific reasons, for political and prestige reasons, or to serve specific military needs) can be adapted, extended, and expanded to use the new environment and nearly limitless resources of outer space for the benefit of humanity in an economically profitable manner. Space industrialization will then grow from a handful of commercially operated communications satellites into a highly diversified and expanding sector of the human socioeconomic system. In the first few decades, however, it will necessarily depend for its very existence on the conventional segments of the socioeconomic system to provide the technology, the original investment capital, and the markets for its goods and services. Thus it is essential to explore the nature and shape of the socioeconomic system as it may evolve in the next few decades before we can realistically examine just what may constitute space industrialization, and how, why, and when portions of the new space industries may arise.

This examination of the terrestrial background has been done in two parts. First, basic macroeconomic projections were made to examine the needs of the human socioeconomic system during the coming decades with respect to basic materials: energy fuels, minerals, and basic agricultural commodities. If the "limits to growth" hypothesis should prove to be correct, then perhaps space industrialization could provide some of the very basic needs of the industrialized societies of the world. Second, a variety of alternative futures were examined to determine how space industrialization might be shaped by events and developments in the rest of the system. The economic profitability, political viability, and social desirability of specific space industrial activities can only be defined in the context of general social, political, economic, and technological factors characterizing an alternative future. These alternative future scenarios also provide some basis for contingency planning and for identifying stepping stones in space technology which are most likely to be useful in any future space programs or activities.

The results of these two parts of our examination of the terrestrial background provided some of the basis for considering the market potentials of various possible space industries and much of the foundation for developing specific examples of possible programs of space industrialization during the next few decades. The necessity for continuous planning of intermediate and long range programs became quite clear from this work. Just as buggywhip manufacturers who did not foresee that self-propelled trucks would make the horse-drawn milkwagon obsolete were soon reduced to financial ruin, proponents of specific possibilities for industries in space may find themselves stranded by changes in the terrestrial background due to new economic, political, social, or technological factors unless they continually dedicate some effort to planning their programs in relation to current developments and trends on Earth.

2.1 RESOURCES ASSESSMENTS

A detailed assessment (case-by-case) of natural resource availability (described in Vol. 2) was made for 18 minerals selected either because of their large volume (such as iron) or because of critical importance to important industrial processes or agriculture (such as phosphate). Fossil fuels were also examined in assessing likely sources of energy in the next three decades. But to assess supply and demand for such commodities, it was necessary to project population growth and trends in basic economic indicators such as GNP and personal incomes. In addition, we have examined the outlook for a number of basic agricultural commodities, albeit in a somewhat simplistic manner.

2.1.1 Conclusions

It does not appear, on the basis of our examination of energy, minerals, and food production issues over the period 1980 to 2010, that any of these will pose any critical threat to the survival of industrial civilization. The spectre of impending scarcities does not, therefore, provide a credible basis for the political support necessary to mount a major thrust into space at public expense on a crash program schedule. The importance of long-range solutions to the problems of energy supply, however, is clear in the discussion above. The economic value of energy

and minerals imported from space may be significant and may provide sufficient motivations for space industrialization; these possibilities should not be dismissed lightly. But their justification, during the period of interest in this study, must be found elsewhere. "Limits to growth" cannot justify space industrialization during the next three or more decades.

2.2 CONSTRUCTION OF ALTERNATIVE SCENARIOS

We have selected a list of ten events or developments which appear to have a reasonable chance of occurring in the next two or three decades and which would be likely to have major effects on the shape of the future. Arranged according to morphological categories, these "triggering" events or developments are as follows:

Extrapolative:

Baseline (for comparison-no "triggering events")

Political:

Major advances in space by other nations.
U.S. commitment to space.

Societal:

Major breakthrough in human longevity.
U.S. disenchantment with space.

Economic:

Entrepreneurial exploitation of space technologies.
Artificial shortages of critical minerals.
Economic collapse due to shortage of capital.

Technological:

Breakthrough in a new energy source.

Environmental:

Human-generated ecological catastrophies.
Rapid cooling of the Northern Hemisphere.

2.2.1 General Observations

The scenarios described here span a wide range of possible futures. While opportunities for the advocacy of a variety of specific space industrialization activities appear in every scenario, many of these opportunities are apt to fall in the private sector rather than in NASA

or other governmental agencies. Because of the strong possibilities of synergisms between various space activities, however, NASA can no more ignore private sector activities and developments than the private sector can ignore NASA plans for development of new launch vehicles. If NASA's efforts are to have the greatest benefit, these efforts must be based on up-to-date understanding of the opportunities for advocacy presented to the private sector and to the whole public sector by developments in the human system as a whole. This requires continuous examination by NASA of the changing opportunities and of the changing fabric of the human system. Planning space industrialization cannot be done effectively if it is done only in fits and starts; the volatility of the human system requires reassessment of alternative futures on a continuing basis to identify, at each moment, what space systems and space technologies are most likely to be used by a wide variety of space industrialization opportunities. Just as short-range planning is done on a continuing, day-to-day basis, mid-and long-range planning must be done continuously to prepare for contingencies.

3. INDUSTRIAL OPPORTUNITIES IN SPACE

The establishment of future markets and a space industrialization program for each future scenario required a compilation of potential opportunities. These were established to a level of detail and breadth of application sufficient to allow gross market survey and preliminary program formulation.

The purpose of this compilation was not to create an exhaustive shopping list of opportunities but rather to key in certain indicative possibilities within each industrial activity identified (Information Services, Energy, Products, People). The goal was of sufficient breadth to insure represensative program formulation and appropriate market survey. The result of this is a compilation of over 200 potential applications for space related goods and services.

As previously noted, the opportunities and their identified representative usage were compiled under four industry activity categories: Information Services, Energy, Products and People (in space). Each of these categories was further subdivided into subcategories as follows.

Information Services	Energy
Communications	Solar Power Satellite
Observations	Redirected Isolation
Navigation	Nuclear Waste Disposal
Location	Nuclear Power/Breeder Satellite
Sensor Polling	Power Relay

Products	People
Biologicals	Tourism
Electronics	Medical
Electrical	Entertainment/Art
Structural	Recreation
Process	Education
Opticals	Support

4. THE TERRESTRIAL ALTERNATIVES

Thirty-two candidates for space utilization were compared to potential Earth based alternatives. Comparisons were based on examining the initial cost of installation on a first order basis and a cursory review of qualitative factors such as ease of use, reliability, technology requirements, etc. If costs and capability obtained appeared comparable between the alternatives, they were retained for further study. In certain instances the identified space uses exhibited much lower cost for similar capability or the reverse. These were identified as clearly viable candidates. Where cost and/or capability were clearly superior for the Earth alternative, the candidate was dropped from further consideration.

For five of the thirty-two the terrestrial alternative was deemed clearly superior, seven appeared more favorable accomplished from space and twenty depended too much on specific details (too close to call).

The generic lessons culminate with the conclusion that alternatives do exist, or can be visualized for most space initiatives. "Uniqueness" of the space candidates detailed was not deemed strong enough to warrant special consideration in a competitive environment. Significant technological "lead" for space options was found only in the area of earth resources. And, in the case of communications, implementation may be tipped already toward terrestrial options. In concert with these arguments it is concluded that market softness, in terms of systems requirements, remove the constraint that terrestrial alternative systems must duplicate exactly space products and services.

The implications of the above statements gives rise to the following observations on the viability of terrestrial alternatives.

1) Complexity from detailed assessment of non-cost issues substantially reduces the opportunity to develop a "winning" mix of space efforts based on generalized benefits.
2) In lieu of a mandate, space viability must be aggressively advocated/studied against competitors in the mid 1980's.

3) The current involvement of an existing industry will typically indicate which alternative would be favored by it unless forced by competition to change directions. New entries in an industry will select a path based on investment and risk considerations. Most space initiatives considered in this study will appear highly favorable over terrestrial alternatives only after steps toward risk reduction are implemented.

5. POTENTIAL MARKETS AND REVENUES

5.1 APPROACH

After compilation of the list of Industrial Opportunities was complete, a review process was undertaken to select initiatives for preliminary market analysis. The primary criteria applied in the screening process were availability of data and probable advantage over terrestrial competitors. Assumptions were made based on the data available after the analysis was underway.

Different specific methodologies were applied according to which industry was being examined. For example, market analyses for Products were much more speculative than those for Information Services since much less is known about the specific use and probable cost of a prospective product. A common set of general methodology guidelines were used wherever appropriate and provide the foundation for understanding the philosophy and assumptions which guided these market surveys.

5.2 AGGREGATION OF MARKET POTENTIAL

One conclusion quickly drawn from the data derived in these analyses is that very large single opportunity revenues are possible in several areas. It follows that aggregates of these potential (or expanded) industries will represent even great possibilities.

As indicated in each market analysis the flow of revenues initiates and evolves based on several assumptions including best case/least case for total market potential at saturation. Thus the actual revenues which might be anticipated in the time period of this study will depend substantially on the background scenarios previously presented. For purposes of analyzing far and near term implications of space industrialization, the time frame of initiation and rate of growth of each industry was adjusted during the analysis.

Although the more exact figures will depend on such specifics as future scenarios and programmatics, it is worthwhile to summarize revenue projections. This will allow interpretation by the reader of the

possible significant of SI in the 1980 - 2010 time period. Summary data are presented below for revenues (best case). The timing shown is considered to correspond roughly to the baseline scenario. All revenues calculated are additive to current SI revenues which total about one billion dollars per year in 1978.

The relative value of each market area (Information Services, Energy, Products and People) as a function of time is presented in Figure 5-1. A more aggressive scenario (implying more aggressive SI programs) basically accelerates the revenue flow and adds more minor initiatives. A scenario without SPS eliminates that portion of the summary and inhibits other activities in the Information Services and Products industries. In the opinion of the SAI study team, given no "surprises", no substantial foreign challenges in space, etc., we can expect space industrialization to evolve as depicted in Figure 5-1.

Inherent to this prediction is a period of capability and technology development in the 1980s leading to expanded exploitation and utilization in the 1990s and intensive growth beyond the year 2000. The resulting interpretation from this is that revenues will approximately double from 1980 to 1990. A very rapid growth in revenue then ensues as technology and hardware development efforts in the eighties come on line in the 1990 to 1995 time period. Although new technologies (particularly in power, structures and transportation) are emerging, the activities settle basically into an implementation and expansion phase with doubling time for revenues becoming approximately five years until the end of the time period of interest.

There appear to be no "natural laws" or technological barriers which would limit revenue growth to the level indicated. Strong response to a foreign challenge or a heavy entrepreneurial initiative in the near future (early eighties) could result in more rapid growth. Potential revenues well over 100 billion (1977) dollars per year appear feasible with technology and development effort acceleration and aggressive marketing.

PROJECTED ANNUAL AND CUMULATIVE REVENUE POTENTIAL FOR SELECTED INFORMATION SERVICES INITIATIVES (1977 DOLLARS)

	POTENTIAL REVENUES (in Millions of Dollars)	
	ANNUAL (PEAK)	CUMULATIVE (1985 - 2010)
INFORMATION SERVICES		
Pocket Telephone	20,000	100,000
Teleconferencing	9,000	90,000
National Information Services	6,000	40,000
Electronic Mail	9,000	90,000
Disaster Communications Set	30	500
Advanced TV Broadcast	2,000	8,000
Vehicle Inspection	300	4,000
Global Search and Rescue	50	300
Nuclear Fuel Locators	3	44
Ocean Resources	2	50
Transportation Services (Equipment Sales)	70	400
Rail And Collision System	40	800
Personal Navigation Sets (Equipment Sales)	100	400
Vehicle/Package Locator	300	5,000
Voting/Polling Wrist Set	40	200
	~ $47B/YEAR	~$340 BILLION

PROJECTED ANNUAL AND CUMULATIVE REVENUE POTENTIAL FOR SELECTED ENERGY INITIATIVES (1977 DOLLARS)

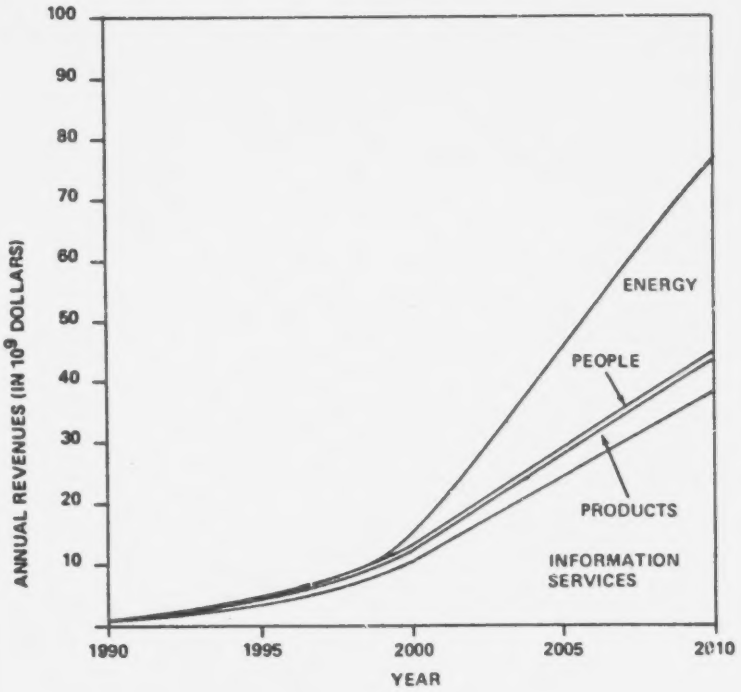
	POTENTIAL REVENUES (in Millions of Dolars)	
	ANNUAL (PEAK)	CUMULATIVE (1985 – 2010)
ENERGY		
Solar Power Satellite (First SAT in 1996)		
49 5GW at 27 MILS/KWH	50,000	300,000
60 10GW at 11.5 MILS/KWH → 7.1 MILS/KWH	30,000	200,000
60 10GW at 27 MILS/KWH	100,000	600,000
Urban Night Illuminator	200	2,000
Nuclear Waste Disposal	1,000	3,000
	~ $30 – $100 B	~ $200 – $600 B

PROJECTED ANNUAL AND CUMULATIVE REVENUE POTENTIAL FOR SELECTED PRODUCTS (1977 DOLLARS)

	POTENTIAL REVENUES (in Millions of Dollars)	
	ANNUAL (PEAK)	CUMULATIVE (1985 - 2010)
PRODUCTS		
Drugs and Pharmaceuticals	600	7,000
Electronics		
Semiconductors	2,000	20,000
Electrical		
Magnets	300	4,000
Superconductor (generating only)	2,000	20,000
Optical		
Fiber Optics	80	800
Special Metals		
Perishable Cutting Tools	800	8,000
Bearings and Bushings	200	2,000
Jewelry	100	2,000
	~ $8 B/YR	~ $84 BILLION

PROJECTED ANNUAL AND CUMULATIVE REVENUE POTENTIAL FOR SELECTED PEOPLE INITIATIVES (1977 DOLLARS)

	POTENTIAL REVENUES (in Millions of Dollars)	
	ANNUAL (PEAK)	CUMULATIVE (1985 - 2010)
PEOPLE		
Space Tourism	50	900
Space Hotel	50	600
	~ $100 M/YR	~ $1.5 BILLION



Note: All values shown are additive to the present (1977) revenues of approximately one billion dollars per year. All Figures are in 1977 dollars.

Figure 5-1. Project Revenues for Space Industry Activities Assuming the Baseline Scenario for Terrestrial Background

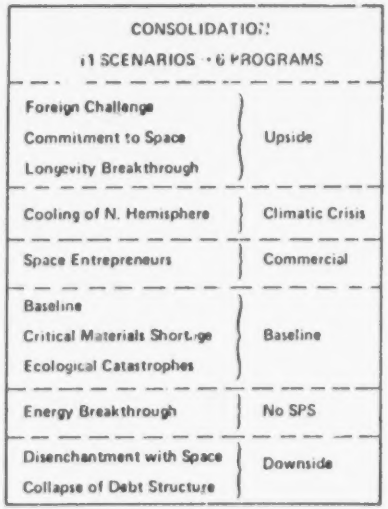
6. SPACE INDUSTRY PROGRAM DERIVATION AND ANALYSIS

The results of the work described in previous sections (Terrestrial Background, Opportunities and Markets) provided the basic information necessary to map out probable courses of future programs. Space Industrialization by definition consists of a multitude of development or operational programs occurring simultaneously or in series. In the first part (Part 1) of this study, the totality of programs was referred to as a "program" for convenience. That terminology has been maintained in this volume in order to distinguish these "program" analyses from the work in Part 2 of the study. In Part 2, SAI and Rockwell Inc. agreed to change the semantics so that the word "Plan" represented the totality of programs.

The flow and interrelationship of various tasks from which programs were derived and analyzed is shown on Figure 6-1 which also summarizes the grouping of eleven scenarios into six programs. The philosophy of this grouping is discussed in Volume 2.

The hypothetical programs we have developed reflect our considered collective judgment of what kinds of space activities are likely to be economically and politically viable in the assumed contexts of the background scenarios. Like the scenarios themselves, these programs should not be interpreted as attempts to forecast the future but rather as explorations of plausible alternatives which can be used to provide reasonable guidelines for long-range planning. This kind of exploration can serve to identify stepping stones which are common to a multitude of alternative futures and to identify systems which are likely to be much more dependent on external contingencies, requiring more careful attention to the course of events.

To scope future costs, impacts and requirements, three programs were selected for detailed analysis. These were the Baseline, No SPS and Upside Programs. The procedure was to take the general programs and just specific timing and scale according to guidelines from the scenarios



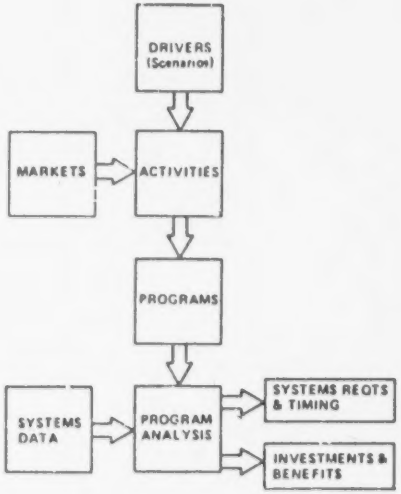


Figure 6-1. Summary of Space Industry Programs Derived and the Steps to Their Derivation and Analysis

and market data. In some cases several initiatives were lumped into a single system for purposes of simplifying costing and scheduling. A platform approach to developing the communications initiatives was assumed.

Introduction and growth of the various Information Services leads to requirements for very large platforms in the nineties and beyond corresponding to the market projections presented previously. This turned out to be the largest single set of industry initiatives in terms of power and structures other than SPS and light reflectors.

The results of the program analysis in terms of structure, power and transportation needs is shown in Figures 6-2 and 6-3.

ACTIVITY	INFORMATION	ENERGY	MATERIALS	PEOPLE
MAJOR SPACE ADVANTAGE	• VIEW • ACCESS	• SOLAR FLUX	• LOW 'G' HIGH VAC • HIGH VAC	• UNIQUENESS
MAJOR TECHNICAL HURDLES	• SIZE 10–100 METER ANTENNA • POWER 21 KW – 10,000 KW • DATA PROC • TRANSPORT COST (OPERATIONS)	• SIZE/MASS OF SYSTEM ~ 10^4 MW ~ 10^5 TONS ~ 10^{10} • TRANSPORT COST < $20/LB LEO • ENVIRONMENT ISSUES	• PROOF OF THEORY • PRODUCTION DEVELOPMENT HUNDREDS OF POUNDS PER DAY • POWER 10 KW – 10,000 KW CONTINUOUS • TRANSPORT COST < $100/LB LEO	• TRANSPORT COST $25/LB OR LESS • HABITATION
TIMING FOR SIGNIFICANT REVENUES	• PRESENT > $1000 M/YR • 1985 + RAPID EXPANSION	• 1996 +	• 1987 +	• 1990 +

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Figure 6-2. A Summary of Qualitative and Quantitative Observations Drawn From the Programs Analysis

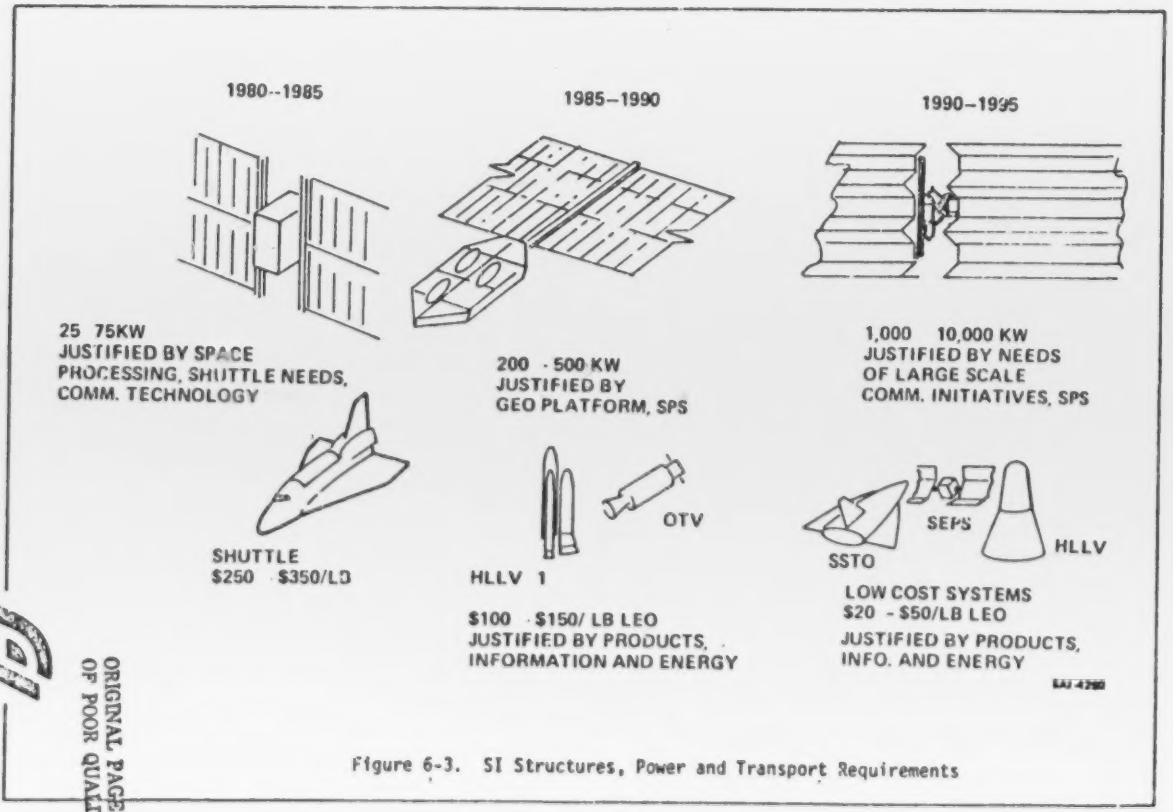

Figure 6-3. SI Structures, Power and Transport Requirements

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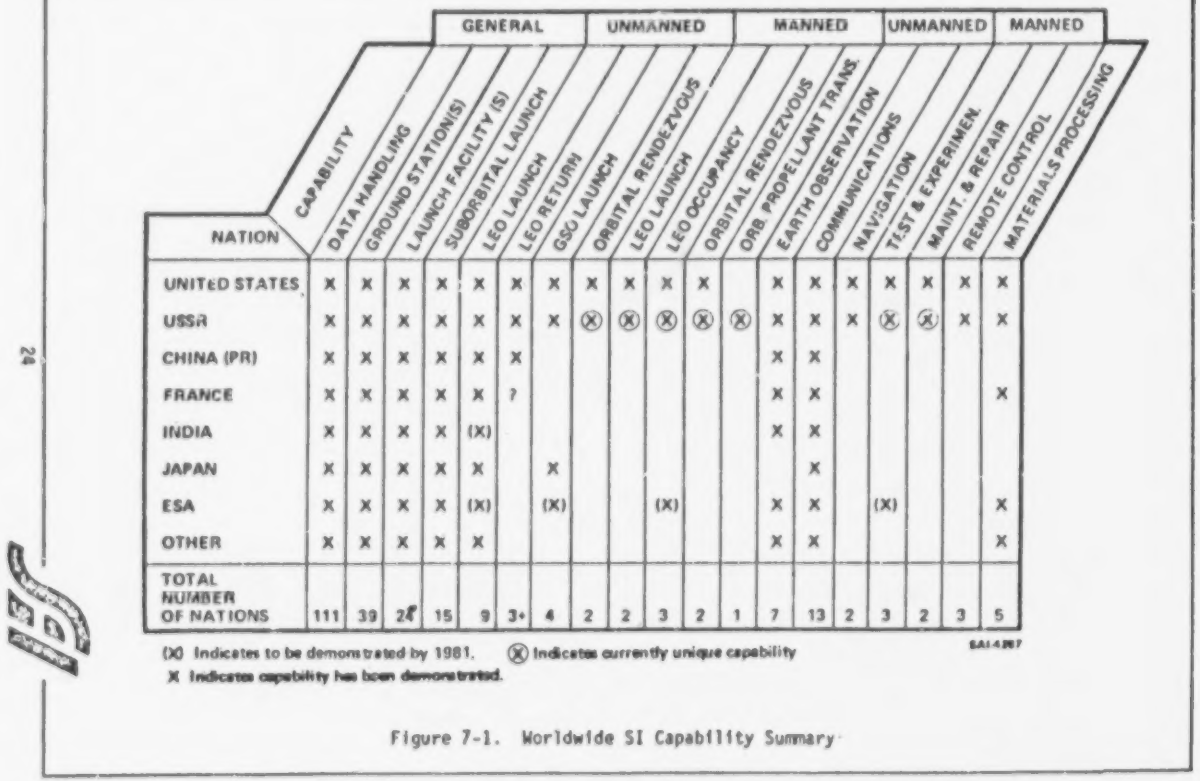
7. WORLDWIDE ACTIVITIES IN SPACE INDUSTRIALIZATION AND THEIR IMPLICATIONS

From military and scientific beginnings some twenty years ago (October 1957 for Sputnik, January 1958 for Explorer) there has evolved a broad and complex industrial base in space. The activities range from basic research in the space processing of materials to the fully operational information transfer systems. The worldwide gross annual revenue now exceeds one billion dollars in sales of services alone. Current published projections indicate that revenues from services by 2010 may reach ten to twenty billion dollars given only minor extrapolations of present technology. With technology advancements in power, structures, transportation, materials processing, frequency use and data handling our study indicates that the potential can be several times that revenue amount. Of the four general categories of space industrialization (Information Services, Products, Energy, People in Space) the area nearest maturity is Information Services. New technologies will be necessary to open up new markets in these services also, however.

The worldwide interest in SI is reflected by the number of countries and agencies that are actively participating at present. This is characterized in Figure 7-1 by summarizing capabilities both previously demonstrated and currently being developed that relate specifically to Space Industrialization.

Why is there such extensive involvement in organizing for and implementing Space Industrialization in the world? In the simplest terms, it appears that needs and markets exist forming the basis for large scale international involvements. This has prompted a wide spread interest and desire for independent capabilities to utilize space and an awareness of the potential benefits from gaining and maintaining a competitive position. In the free world the US will be challenged through the eighties in all technologies including those that are peculiar to manned space flight. The recent capability demonstrations of the USS aboard Salyut 6 and the strong reports of their current development of a reusable shuttle leave no doubt that major technical achievements can be anticipated by communist bloc countries in SI throughout the eighties.



NATION	CAPABILITY	GENERAL: DATA HANDLING	GENERAL: GROUND STATION(S)	GENERAL: LAUNCH FACILITY (S)	GENERAL: SUBORBITAL LAUNCH	GENERAL: LEO LAUNCH	GENERAL: LEO RETURN	GENERAL: GSO LAUNCH	UNMANNED: ORBITAL RENDEZVOUS	UNMANNED: LEO LAUNCH	UNMANNED: LEO OCCUPANCY	MANNED: ORBITAL RENDEZVOUS	MANNED: ORB. PROPELLANT TRANS.	MANNED: EARTH OBSERVATION	MANNED: COMMUNICATIONS	UNMANNED: NAVIGATION	UNMANNED: TEST & EXPERIMEN.	MANNED: MAINT. & REPAIR	MANNED: REMOTE CONTROL	MANNED: MATERIALS PROCESSING
UNITED STATES	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
USSR	X	X	X	X	X	X	X	Ⓧ	Ⓧ	Ⓧ	Ⓧ	Ⓧ	X	X	X	Ⓧ	Ⓧ	X	X	X
CHINA (PR)	X	X	X	X	X	X							X	X						
FRANCE	X	X	X	X	X	?							X	X						X
INDIA	X	X	X	X	(X)								X	X						
JAPAN	X	X	X	X	X		X							X						
ESA	X	X	X	X	(X)		(X)			(X)			X	X		(X)				X
OTHER	X	X	X	X	X								X	X						X
TOTAL NUMBER OF NATIONS	111	39	28	15	9	3+	4	2	2	3	2	1	7	13	2	3	2	3	5	

(X) Indicates to be demonstrated by 1981. Ⓧ Indicates currently unique capability

X Indicates capability has been demonstrated.

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Figure 7-1. Worldwide SI Capability Summary

8. DOMESTIC IMPACTS AND ISSUES

Space Industrialization (SI) will have impact and meaning in many areas of human endeavor in the United States as well as the world. These impacts may be more subtle than profound, given the level of economic and technical development already enjoyed by the U.S. Nonetheless, these impacts will be important and, indeed, can provide the stimuli necessary to assure U.S. economic growth through the last decade of this century and into the next. The realization of these impacts in a positive fashion will depend completely on establishment of government roles supportive to greatly enhanced private sector involvement in space.

8.1 EMPLOYMENT AND ECONOMY IMPACTS

The economic impacts examined in this study were based on an alternate approach to simple trend extrapolation. From the scenario, market and program work reported in Volume 2, it was surmised that significant opportunities existed in the near future in the public and private sector. If advantage is taken of these opportunities, a much greater benefit to the U.S. and world can be realized than would be predicted by simple trend forecasting. Thus the analyses whose results are presented here were structured to show what could happen, and hopefully help precipitate the required actions. As mentioned in the discussion on Future Scenarios (Volume 2), an implicit assumption in all analyses was that opportunities would be capitalized on, the extent of which varied between scenarios. This is reflected in the six programs developed and presented in Volume 2 and more specifically in the two programs analyzed in detail. The following benefit calculations are based on those analyses.

8.1.1 Assumptions

Certain assumptions concerning the nature of the industries involved in stimulating and handling the revenue flows were necessary. Composite indices were developed and applied across the board without specific variation between industry types, products vs. services, etc.

Given the composite nature of the expenditures and revenues on a whole program basis and our uncertainties, even detailed indices would yield aggregate approximations. Thus a more detailed industry-by-industry assessment is not warranted until more specific analyses are performed on the projected revenues and costs.

The specific indices used were:

$$\frac{\text{BEFORE TAX PROFIT}}{\text{GROSS REVENUE}} = 0.20$$

TAX BRACKET = 0.50

LABOR INTENSITY (OPERATIONS AND MAINTENANCE) = 0.40

COMPOSITE MEAN SALARY = $17,000 ANNUAL

These figures are typical of various service industries today subject to government regulation. Although profit margin for COMSAT was somewhat higher in the past, the trend has been to force it downward. As discussed in Section 6 of Volume 3, after tax profits have varied from six to fifteen percent typically.

Current corporate taxes are 49 percent. For simplicity, a straight 50 percent was used.

Calculations were performed for two points in time. First, 1985 was selected as a representative near term year where almost all new revenue in SI would be investments. This was assumed to be almost purely public funding (government sponsored development programs). The latter year chosen was 2010, the end of the time period being examined (1980-2010). The revenue in 2010 is projected to result almost entirely (>95%) from sales of Services, Products and Energy (People in Space revenues are insignificant compared to the others).

8.1.2 Results

Jobs and taxes generated were estimated for three programs: the Energy Breakthrough (No SPS), the Baseline (with SPS), and the Upside (all initiatives). Although the Upside is considered the least likely of the three (requiring heavy investment in the early eighties), it was desirable to assess the potential impact of such a strong,

aggressive set of initiatives. The results were as follows:
(For comparison with the companion Rockwell International report on SI, the NO SPS corresponds to Plan C, BASELINE to Plan A. An UPSIDE type program was not addressed by RI.)

	NEW JOBS*		
	NO SPS	BASELINE	UPSIDE
1985	15,000	100,000	120,000
2010	1,000,000	1,900,000	3,800,000

	TAXES GENERATED*		
	NO SPS	BASELINE	UPSIDE
1985	$ 100M	$ 800M	$ 1000M
2010	$10,000M	$ 20,000M	$40,000M

* DIRECT ONLY. U.S. MARKETS ONLY

The estimate of jobs for 1985 is probably low by a factor of two since most funding would be to the aerospace industries. The Aerospace Industries Association (AIA) has estimated that about 30 direct jobs are created for each one million dollars of appropriation. Direct plus indirect jobs are estimated to total about 100 jobs per one million dollars. Thus the job projection for 1985 is conservative since the computation was the same as for 2010. The true impact on new jobs is some two to four times the numbers shown here depending on specific assumptions and economic theory applied.

In the aggregate, the best guess is that 75% or more of the postulated SI initatives revenues will be job creating in the nineties and beyond. Thus for a workforce of 100,000,000 in 2010 some three to twelve percent could be employed in new jobs created by space industrialization.

The tax revenue calculations take into account corporate taxes based on previous assumptions plus personal income taxes of direct employees. A national composite rate of 0.26 for federal and state income tax was applied to personal income.

8.2 SAMPLE INDUSTRY COMMENTS AND RECOMMENDATIONS

Industry representatives involved in private enterprise in the three major categories (Information Services, Energy and Products) were contacted. The purpose was to obtain information on how government and industry could cooperate and complement in order to make space industrialization grow.

The contacts consisted of:

Information Services - two contacts in the satellite communications business.

Energy - two contacts in power R & D
- two contacts in the investment community

Products - nine contacts in non-aerospace manufacturing

At present a corporate leader/manager cannot justify any investment in products (at the basic research stage and having much too high transport costs) or energy (overwhelming techno-economic risk). The more expensive communications systems (such as the Orbital Antenna Farm of Morgan and Edelson, COMSAT) are being looked at rather seriously, although the total capital and payback times on larger systems look doubtful (see Section 6, Volume 3). One simple message is certain. As techno-economic risks come down, U.S. industry will steadily increase its allocation of resources to SI if a reasonable payback can be obtained. "Reasonable payback" will vary broadly based on initial investment, near term vs. long term risk, guarantees, etc.

8.2.1 Industry Views on Roles and Responsibilities

The specifics of appropriate roles and responsibilities which could be adopted by industry and government vary broadly according to the industry and the individual. It is possible, however, at the rather gross segregation level presented in Figure 8-1 to assemble a set of consensus opinions. As might be anticipated the communications industry is sufficiently mature that the Product Development and Pilot Operations areas require consideration of specific proposals to obtain a particular opinion. The large geo platform concept was one initiative that generally fell in the joint venture category

INDUSTRY IDEAS ON ROLES & RESPONSIBILITEIS

C – COMMUNICATIONS
E – ENERGY
P – PRODUCTS

	GOVERNMENT ACTIVITY	INDUSTRY ACTIVITY	JOINT VENTURE	GOVERNMENT REGULATION
BASIC RESEARCH	C E P			
APPLIED RESEARCH	E P		C	
PRODUCT DEVELOPMENT	E	C*	C* P	
PILOT OPERATIONS	E	C*	C* P	
PRODUCTION OPERATIONS		C E P		C E
TRANSPORT DEVELOPMENT	C E P			
TRANSPORT OPERATIONS		C E P		C E P

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*DEPENDS ON SPECIFICS

Figure 8-1. Industry Views on Roles and Responsibilities

for example. A new version of an existing satellite system was considered to be an appropriate industry activity. Particular attention is drawn to the consensus or CEP blocks.

The information presented here is considered as a stage setting providing general guidelines for development of specific arrangement on a case by case basis. Early general agreement to these guidelines by government would encourage enhanced industry involvement in space industrialization.

Specific concerns and recommendations from industry were compiled into a rather extensive list. These are presented in Volume 3.

9. LEGAL CONSIDERATIONS

The legal considerations which must be recognized in any broad examination of space industrialization are, at first glimpse, staggering in their number and complexity. Entire symposia and extensive sessions during various astronautical conferences have been devoted to deliberations on interpretation of existing and proposed agreements, treaties, statutes, etc. In this study, there was no attempt to provide legal interpretations of laws and agreements. Instead, expert opinion was relied on to ascertain the answers to two simple questions: Are there any international laws or agreements which would preclude or severely limit evolution of any of the SI initiatives discussed in this study? Are there domestic laws (in the U.S.) with similar potential for limitation?

At present, space industrialization is not suffering substantially from either international or domestic legal constraints. The large scale initiatives discussed in this report for implementation in the 1980 - 2010 period could all be exercised today within the legal structure. However, all indications are that a series of initiatives to limit the U.S. and its industry are in existence or being originated. A net effect of these in the light of no established national policy in this arena will be to increase economic risk and foster impediment to industry involvement in SI. Without steps to assure industry in these matters, space industrialization may falter regardless of economic and technological enticements.

10. INSTITUTION IMPLICATIONS

A host of institutions ranging from religious to technological will be affected by space industrialization. Their influences on the growth of SI and the specific opportunities which will be capitalized on vary greatly, of course. From discussions with industry contacts, investors, lawyers and national politicians there emerged a basic set of considerations which form the back drop for detailed analysis of key institutional implications.

These items, termed "Five Significant Considerations", are:

1. Space industrialization must become an integral part of national space policy planning.
2. Industrializing organizations and legal structures must evolve and be encouraged.
3. Mechanisms for advantageous transfer of responsibility necessary.
4. The applicability of SI technologies to many problems, needs and markets will go unnoticed without focused dialog.
5. The knotty issues of today in technology export will be further driven by the international/multinational nature of SI.

The government/industry/academic institutional arrangements necessary to accomplish tasks 1 through 3 and optimize benefit from 4 and 5 must be designed in a fashion responsive to the needs of individual SI initiatives. The first steps can be taken, however, by establishing a planning office responsible for the integration of space industrialization elements into all national space activities and plans. This office could supply the data for decisions on items 4 and 5 and formulate plans and focus for accomplishing items 2 and 3 as well as continually project, monitor and assess the implications to a broad family of institutions. Such data should prove invaluable to government and private decision makers alike.

11. CAPITAL REQUIREMENTS AND ECONOMIC VIABILITY

From the revenue analyses reported in Volume 2 of this report it appeared that substantially increased interest in SI might be forthcoming in the investment community. Such interest would result not only from revenue potential but also from initial investment, cash flow, pay-back time, project rate of return and similar considerations. Although such analyses were desirable in all industrial areas considered (Information Services, Energy, Products and People in Space) certain limitations and pertinent factors had to be recognized. Specifically, the rapid developments in evaluations of the economics of space based power, the lack of detailed knowledge on product characteristics, and the dependence of People in Space activities on development of other industries precluded reasonable economic assessments in this study. Thus Information Services was the industrial area selected for assessment of these more detailed economic factors.

Five initiatives in Information Services represent over 90% of the potential domestic revenue from space in Information Services (see Section 5.8, Vol 2). These are:

1. Portable Telephone
2. Teleconferencing
3. National Information Service
4. Direct Broadcast TV
5. Electronic Mail

The large potential market for these services was taken as a natural indicator of private investment potential.

The first multi-use Geosynchronous Platform to provide market entry into the five services is shown in Figures 11-1 and 11-2 (courtesy of Rockwell International). This design provided the basis for development and initial operational cost assessment. As the markets develop into the 1990s and beyond, larger versions of the same type system were assumed.

The specific functions provided by this early satellite are as follows:

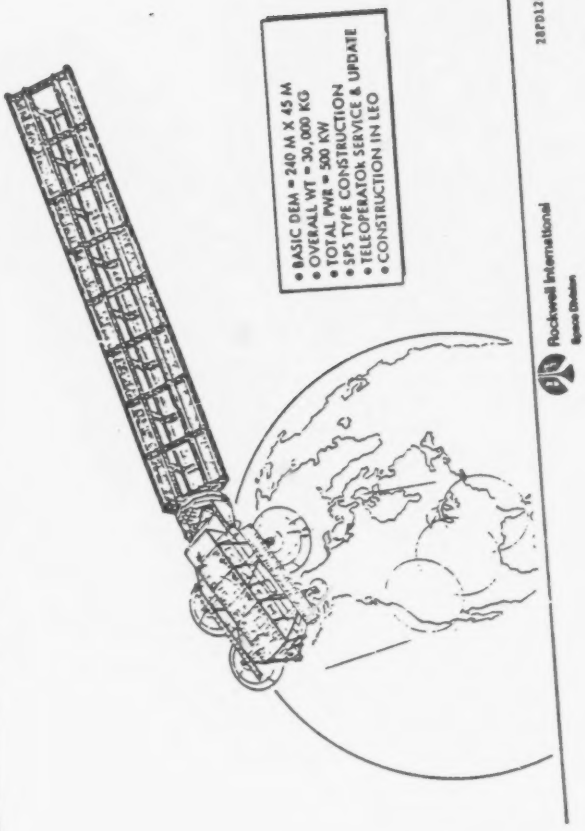
• BASIC DEM = 240 M X 45 M
• OVERALL WT = 30,000 KG
• TOTAL PWR = 500 KW
• SPS TYPE CONSTRUCTION
• TELEOPERATOR SERVICE & UPDATE
• CONSTRUCTION IN LEO
Rockwell International
Space Division
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Figure 11-1. 500 KW Geosynchronous Platform

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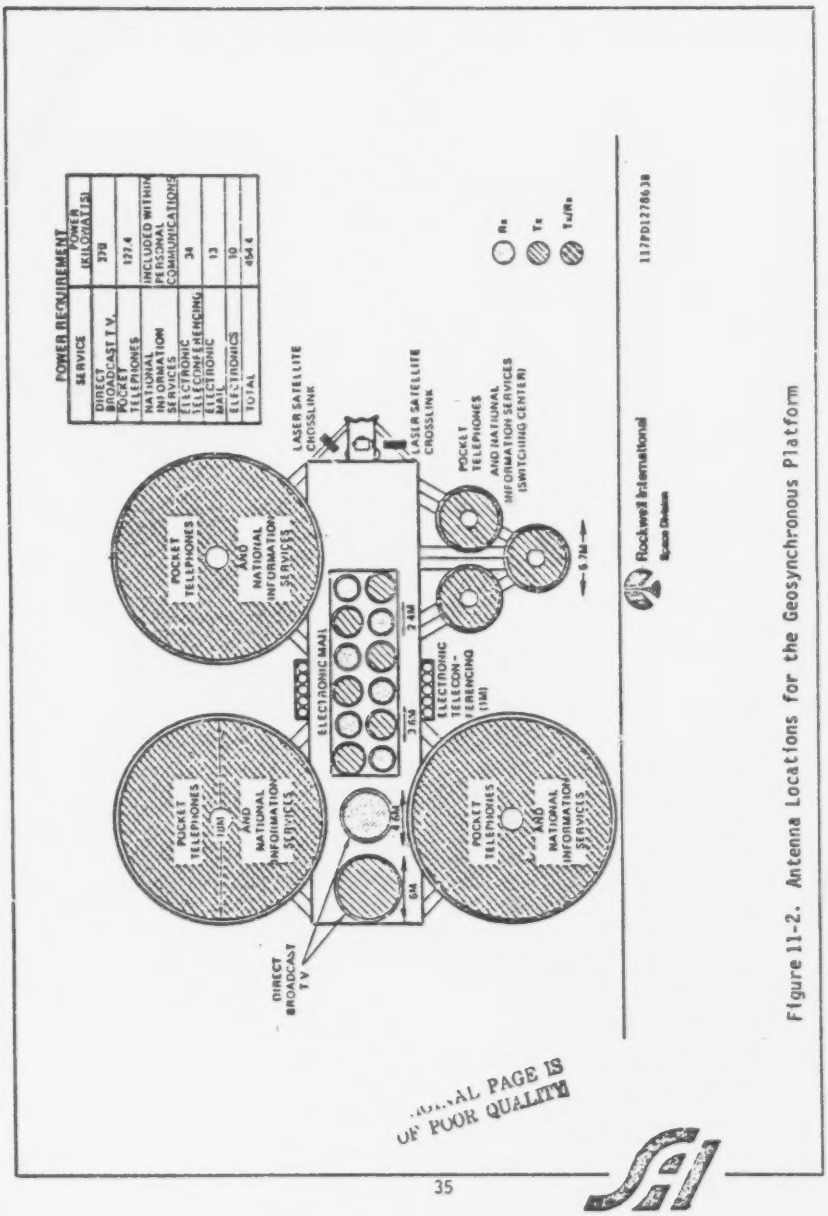

Figure 11-2. Antenna Locations for the Geosynchronous Platform

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The specific functions provided by this early satellite are as follows:

1. Direct broadcast television - Five simultaneous color video channels 16 hours per day to be received on modified, conventional TV receivers. The entire CONUS area is to be covered (excluding Alaska, Hawaii, and Puerto Rico).

2. Pocket telephones - Multiple voice channels originating from remote, wireless extensions; to be connected to conventional fixed terminals or other remote terminals via satellite. Saturation capacity to be at least 45,000 simultaneous transactions.

3. National information services - Direct access via satellite from home or business *intelligent terminals* to computer-supported data banks, such as the Library of Congress.

4. Teleconferencing - Two-way (or multiple) video links between as many as 300 ground sites simultaneously (150 conferences). User locations would have studio-type facilities, including multiple cameras and monitors, switch gear, and communications.

5. Electronic Mail - Facsimile transmission of personal and business correspondence. Terminals would be located in regional postal centers. The regional centers would be interconnected via satellite. Each regional postal center would contain equipment to convert hard copy to electronic facsimile, and vice versa. The ultimate goal is to deliver 40 million pages (8½ x 11) from source to destination over night.

Comparisons to current communications industries were made to derive average figures for net profit margin and non-hardware operational expenses. Rockwell International, in the companion study to this one, derived hardware costs related to these five initiatives for the first platform. Using market projections from Part 1 of the SAI study we derived a prediction of channels needed and sized the space systems requirements and estimated production and deployment costs as a function of time. With all the required cost data together a string of projected costs and revenues was calculated.

In the table below, the "Initial Capital" requirement reflects that amount of money required to establish the service and initiate revenue income. "Capital Before Breakeven" reflects the maximum debt incurred (cumulative cash flow) prior to the cash flow break even time when outlay and income balance. "Rate of Project Return" is an investment judgment tool which allows comparison of economic benefit gained relative to other potential investments. A return of 10% would mean that the investor is breaking even relative to a 10% discounted investment. All figures quoted are computed against a positive future scenario assuming needed structures, power and transportation technologies will come to pass.

SERVICE	INITIAL CAPITAL	CAPITAL BEFORE BREAKEVEN	RATE OF PROJECT RETURN
PERSONAL COMM	$420M	$420M	14%
ADVANCED TV	$200M	$200M	17%
NATIONAL INFO	$420M	$620 – $640M	17%
TELECONF	$254M	$2126M	11%
ELECTRONIC MAIL	$4,260M*	—*	—

*STRONG FUNCTION OF ASSUMPTIONS. BREAKEVEN NEVER ACHIEVED FOR POST OFFICE TO POST OFFICE SYSTEM ASSUMED HERE.

The string of costs and revenues are presented graphically in Figure 11-3 with the number of years to achieve breakeven specified. It was not possible in this study to optimize the R&D investment, debt, market penetration rates, technical synergy and other factors affecting these curves. Also, a more aggressive market scenario could easily lead to economies of scale not realized here. Thus we feel the time to breakeven is generally conservative although not unattractive considering the tens of billions of dollars potential annual revenue.

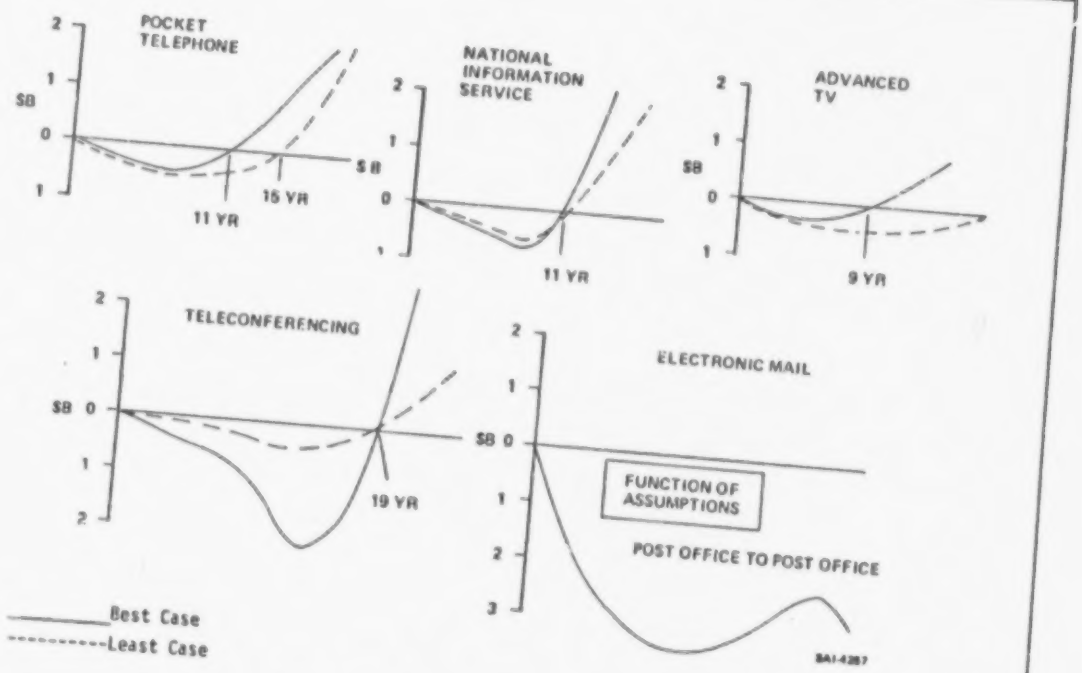

Figure 11-3. Cumulative Cash Flow Requirements

12. OBSERVATIONS AND RECOMMENDATIONS

Many of the results of this study are contained in the various sections of this report as data, observations or conclusions. Recommendations gleaned from outside sources (the industrial contacts) are presented in Volume 3. The purpose here will be to summarize data of particular interest to NASA and the industrial community and present a simple set of recommendations designed to promote the growth of Space Industrialization (SI).

12.1 OBSERVATIONS

Figure 12-1 summarizes the How and Why of Space Industrialization. The roles and related activities of government and industry feed the integrated SI activities that represents the summation of all future private and public SI programs. The motivators for such input and sponsorship are shown as a feedback loop. Three encompassing benefits to the public at large are shown as the integrated "value generation" of space industrialization. Net value generation is possible because a new and virtually inexhaustable resource, loosely called "space", is being utilized.

The corollary consideration of What and When are primarily addressed in Volume 2. At the highest aggregation level (general industrial category) the what and when can be displayed as in Figure 12-2. The rather sterile lines on this figure are wholly inadequate to express the latitude that each has according to the scenario assumed and the realities of capitalization and investment. Also the natural or "organic" growth potential of existing space industry (such as Intelsat and COMSAT) are not reflected on Figure 12-2. Thus the potential exists for the curves of each industry to swing toward greater or lesser revenue or benefit. We can say with some confidence that the direction and magnitude of that swing will depend completely on the investments made in the eighties. The technological, legal, institutional, international and regulatory hurdles must all be overcome in concert. The most important, however, is technological. The incentives are sufficiently strong. That, given technical capability, the other hurdles will be overcome. The future of the United States and our system of free enterprise and democracy demand it. Therein lies the challenge to the NASA, the free worlds technological leader in space.

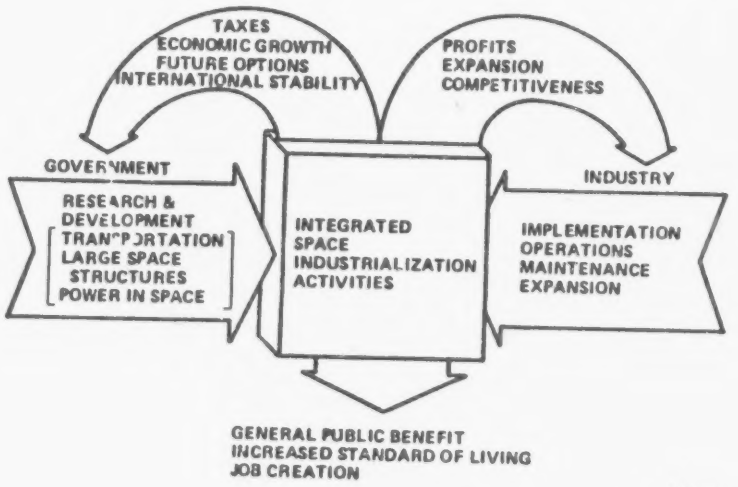

Figure 12-1. The How and Why of Space Industrialization

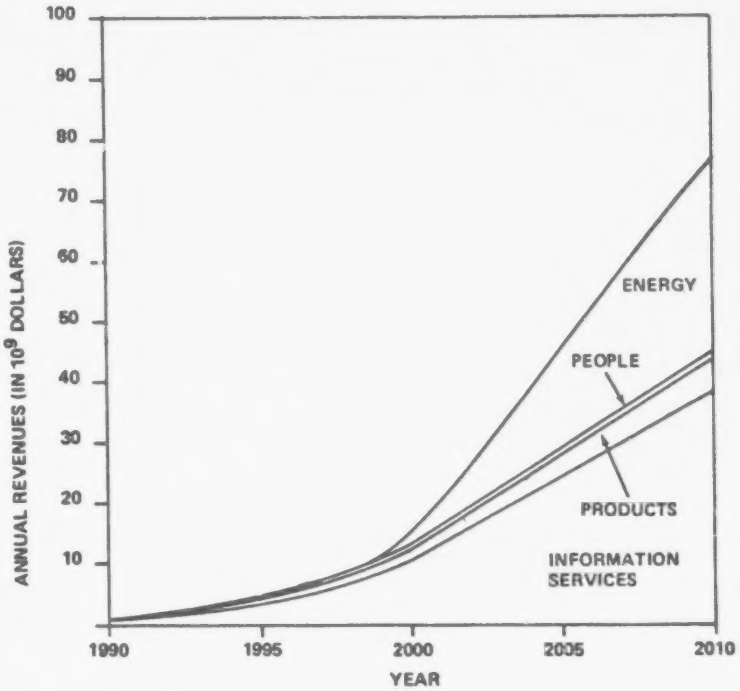

Figure 12-2. The Baseline Scenario Projection of What Space Industrialization Will Be Composed of and When Revenues Will Result

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12.2 KEY TECHNOLOGIES

The most important spur to U.S. industry and U.S. world technical leadership will result from development of the following key technologies.

1. Large information systems
   - Structures - Large antenna of 10M to 200 M diameter.
   - Power - 20 KW to 10,000 KW.
   - Data processing - 100 to 1000 times present rate.
   - Transportation to high orbit - routine for maintenance, repair.
2. Materials space processing
   - Laboratory demonstration - goal oriented spar, spacelab.
   - Prototype production - 10 to 100 pounds per day on some products.
   - Orbital support systems - power, structure, stability
   - Low cost transportation to low orbit -<$100/pound to really open market.
3. Large energy systems (use in space, broadcast to earth)
   - Structures - 0.5 KM to 15 KM
   - Power handling - 25 KW to 10 GW
   - Low cost transportation to high orbit - minimum feasible cost.

The projected benefits depend upon commercial operations that can only begin after the key technologies are available. The potential benefits are significant covering a spectrum of national concerns from jobs and balance of trade through standard of living and national pride.

Analysis of future scenarios, markets and resultant programs show that the result will be:

- Millions of jobs created
- Significant national economic growth
- Assurance of a long term favorable balance of trade
- Increased national and world-wide standard of living
- An enrichment of national pride and aspirations
- An invaluable option bank for responding to unforeseen future events

- Increases in knowledge probably unparalleled in the history of civilization

With the shuttle, we have the basis for space industrialization. We can utilize our lead by proper planning and timely implementation. The alternatives are clear---expanding the U.S. economy or face growing international competition.

In summary, the following points support an aggressive coordinated set of space industrialization initiatives in the public and private sectors.

- The revenue potentials exist today--we only lack the systems.
- All industries examined are exportable--the sooner they are available, the sooner we reap the benefits.
- Near term expenditures will create jobs, spur the economy, and be non-inflationary while creating the future.
- The times are right--if we wait they may not be.
- We can not exploit the shuttle if we don't know where we are going.
- Serious international competition is rapidly building.

The U.S. should begin actively supporting space industrialization by producing a major space power system, initiating the development of systems to support orbital manufacturing and developing large information systems. Substantial space power is needed for almost any industrialization. Materials manufacturing in orbit will require considerable demonstration and supporting systems. Large space information systems look the most commercially viable but the orders of magnitude scale-up needed will require demonstration, and legal constraints (e.g., frequency allocations) may prove very troublesome.

This study has shown that commercially viable industries in Information Services, Energy and Products can be realized given the tools illustrated in Figure 12-3 for private enterprise to work with. Our analysis has also shown that public investment in these capabilities in the eighties will be paid back manyfold in the nineties and beyond. All indications are that Space Industrialization is the stimulus required to swing the United States and the world upward toward the next plateau of human

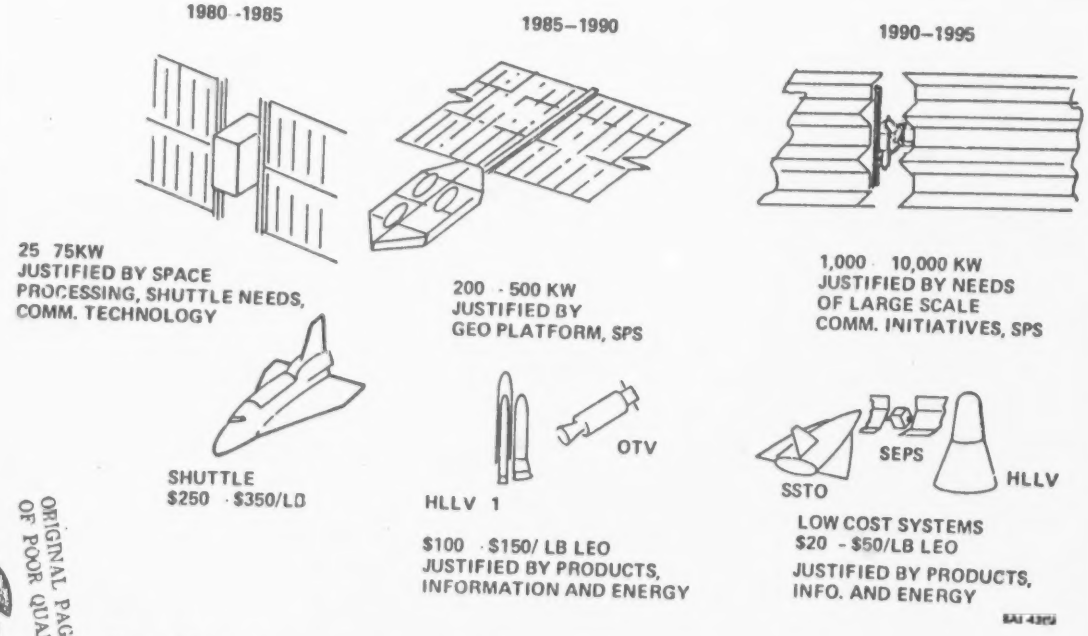

Figure 12-3. SI Structures, Power and Transport Requirements

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achievement. This will be achievement in toto, not just in space or on the Earth but throughout the sphere of human endeavor. We believe that implementation of our recommendations and aggressive pursuit of the overarching concept of Space Industrialization will be concrete steps toward realization of these achievements.

12.3 RECOMMENDATIONS

The following paragraphs contain a series of "key recommendations" that are central to the issue of enhanced SI growth. A broad spectrum of recommendations were formulated, most of them very obvious in derivation. An example might be: "Develop close working relationships with other government agencies and apply SI to their problems and needs." Such recommendations, although central to some aspects of SI growth, are so obviously important that they are already being pursued.

The recommendations presented here, both general and specific, were selected based on their implementation implications. An inherent assumption is that a desire exists to take some predetermined actions to promote the growth of Space Industrialization. Given that assumption, a framework was formulated to provide overall planning guidance and more specific near term steps.

12.3.1 General Recommendations

In the simplest statement, these recommendations are as follows:

- Establish goals for SI in concert with various government agencies and private industry. Most will be in the eighties but some must be identified for the nineties and beyond to obtain overall guidance.
- Plan for the involvement of, and transition to, private industry at the earliest opportunity of all SI initiatives with public services becoming a customer. Consensus opinion is that this will maximize public benefit.

Space Industrialization is, as Ehricke termed it, the overarching concept capable of encompassing and coordinating future applications of space in the most beneficial manner. The individual initiatives in the industrial activities identified in this study should not be pursued as autonomous projects unto themselves. This study has shown that the concepts

of Space Industrialization are viable; that synergistic relationships are possible and desirable; and that industry/government cooperative planning and implementation are desirable and feasible. For various reasons industry will be loath to establish long term goals that carry near term investment commitments, thus government must lead in planning. The assumption of authority and responsibility by industry at an appropriate point in the life cycle of an initiative will require operating characteristics that should be established as part of the design and development process. In this area, industry must lead.

12.3.2 Specific Recommendations

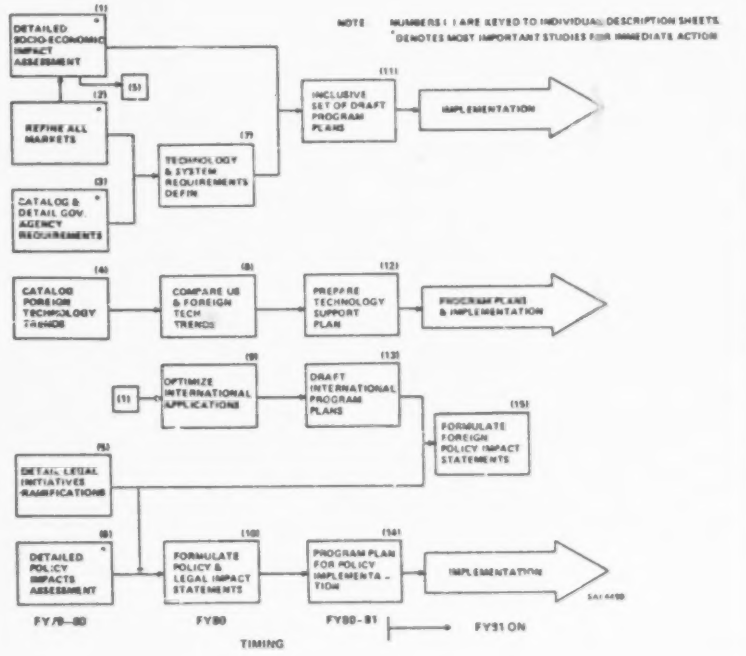
- Incorporate in planning and act on all private industry recommendations discussed in Volume 3.
- Establish an office for SI planning, integration and implementation reporting to the NASA Administrator.
- Conduct the series of studies and formulate/implement the plans shown on Figure 12-4. The subjects and sequences are designed to converge on answers to questions delineated here.

The recommendations most strongly expressed by our industry contacts are presented in Volume 3. Although the level of specificity varies, they are all expressions of a positive nature intended to enhance the near and long term growth of space industrialization.

One recurring message has appeared throughout this study when the origins and reasons for success of various projects was examined. It is that three elements were recurrent. They were:

1. The concept was technically sound.
2. Its evolution was well coordinated and the concepts and developments involved widely displayed.
3. Strong advocacy was provided by a small group of well informed, hard working people.

In recent years a fourth element has often been required: application to an immediate need, although there are notable exceptions in recent years in the scientific community. It is these general observations that prompt our recommendation that a special Office for Space Industrialization Planning, Integration and Implementation be established to focus SI efforts.


NOTE NUMBERS ( ) ARE KEYED TO INDIVIDUAL DESCRIPTION SHEETS
* DENOTES MOST IMPORTANT STUDIES FOR IMMEDIATE ACTION
(1) DETAILED SOCIO-ECONOMIC IMPACT ASSESSMENT *
(2) REFINE ALL MARKETS *
(3) CATALOG & DETAIL GOV. AGENCY REQUIREMENTS *
(5)
(7) TECHNOLOGY & SYSTEM REQUIREMENTS DEFIN
(11) INCLUSIVE SET OF DRAFT PROGRAM PLANS
IMPLEMENTATION
(4) CATALOG FOREIGN TECHNOLOGY TRENDS
(6) COMPARE US & FOREIGN TECH TRENDS
(12) PREPARE TECHNOLOGY SUPPORT PLAN
PROGRAM PLANS & IMPLEMENTATION
(9) OPTIMIZE INTERNATIONAL APPLICATIONS
(13) DRAFT INTERNATIONAL PROGRAM PLANS
(15) FORMULATE FOREIGN POLICY IMPACT STATEMENTS
(14) DETAIL LEGAL INITIATIVES RAMIFICATIONS
(8) DETAILED POLICY IMPACTS ASSESSMENT *
(10) FORMULATE POLICY & LEGAL IMPACT STATEMENTS
(16) PROGRAM PLAN FOR POLICY IMPLEMENTA - TION
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FY80-81
FY81 ON
TIMING

Figure 12-4. Recommendations for Study and Planning Activities Leading to Implementation of SI Programs

Figure 12-4 provides a coordinated view of the individual assessments and planning actions which must come together to promote aggressive SI developments in the eighties. A number in parenthesis with each block keys that activity to the detailed description provided in Volume 3. In column one, certain activities have been marked with an asterisk. This denotes studies and assessments of particular importance which should be initiated first if funding or other constraints preclude addressing all of the FY79 list.

The elaborations in Volume 3 provide not only purpose and description but also duration and level of effort which appear appropriate for each activity. These figures are based on experience and judgment developed during this study relative to the difficulty of addressing a particular subject. Hard charging, positive, aggressive program management is assumed in each case.

The overall implementation concept of Figure 12-4 is sound and proceeds as follows:

First, expend sufficient effort to delineate in detail the requirements and problems.

Second, integrate the requirements and find solutions to the problems.

Third, obtain agreements, funding and policy support.

Fourth, implement the plans and programs.

Fifth, continue planning but maintain long term goals.

The details of Figure 12-4 will undoubtedly change as new knowledge is gained. Without such an overall plan and an orchestration of government involvement in SI the sum of benefits that can accrue to the United States probably will not. It appears that private industry can not step up to the total challenge. If the public sector does not, then we are probably witnessing one of the key non-actions leading to the general demise of the United States as a future technological leader. Unless space begins in less than ten years to generate a highly visible return on investment, we can expect an even greater public disinterest than we have previously experienced. At that point the shuttle will be considered a fraud and the whole concept of Space

Industrialization just another way to flim-flam the politicians into wasting money to keep overpaid bureaucrats on the payroll.

Our perceptions from talks, meetings, newspaper articles, etc. from all over the country is that we are being given the "benefit of the doubt". That will not last forever, probably only three or four years into the shuttle era. It will be necessary to extend that horizon to allow the key technologies to mature and really penetrate the commercial applications arena. That time can be gained through two approaches: (1) Implement experimental programs for the early-to-mid-eighties with strong public appeal and visible results. (2) Promote extensive industry/government involvement in every possible area. This will provide evidence that Space Industrialization is real and a genuine goal of the government agencies involved.

Space Industrialization exists and will grow. How rapidly and to what saturation level are the key questions. Acting on our recommendations will assure near optimum growth patterns, benefiting the United States and humankind in general.

Goddard Space Flight Center

Remarks to National Aeronautics and Space Administration Employees at the Facility in Greenbelt, MD. August 30, 1984

The President. Thank you, Jim Beggs. I'm a little self-conscious right now about arriving in kind of an old-fashioned way—in a helicopter. And after what I've seen here, I'm even more self-conscious about the fact that I'm a captain of the horse cavalry. [*Laughter*]

But I'm delighted to be with you today and to have this chance to say congratulations on this morning's lift-off of the *Discovery* mission. I'm honored to meet all of you who are making this great adventure happen. You've sparked the dreams and imagination of the Nation—from the youngest boys and girls in classrooms across our country to individuals like myself who are approaching the outer limits of their middle-age years. [*Laughter*]

You go quietly about your work, far removed from the glare and the gloss and the glitter of public spotlights. But what you do is important. You're expanding our wealth of knowledge, and with that knowledge, you're fueling a mighty tide of progress, carrying the hope of an optimistic future for people here and everywhere.

Yours is the work of a true revolution; not a revolution poisoned by hatred and violence and the will to conquer, but one that's rising from the deepest yearnings of the human spirit that challenge the limits of knowledge and to put the power of discovery at the service of our most noble and generous impulses for decency, progress, and, yes, for peace.

Today, on behalf of a grateful nation, I salute you and your colleagues in private enterprise and the academic world. You're the heroes of high-tech; the pulse of Ameri-

Reproduced from Reagan, Ronald. Goddard Space Flight Center; remarks to National Aeronautics and Space Administration employees at the facility at Greenbelt, Md., Aug. 30, 1984. Weekly Compilation of Presidential Documents, v. 20, Sept. 3, 1984: 1197-1200.

ca's technological power; the champions of a confident people whose faith and courage are pushing America up and out to a world of wonders for us, our children, and our children's children.

The space age is barely a quarter of a century old, but already we have taken giant steps for all mankind. And our progress is a tribute to American teamwork and excellence. We can be proud that we're first, we're the best; and we are so because we're free.

There's nothing that the United States of America cannot accomplish, if the doubting Thomases would just stand aside and get out of our way. In a single generation, we've freed ourselves from the bounds of Earth; we've set our footprints on the surface of the Moon; we've used our instruments to explore space, the Sun, and our sister planets; and our space shuttle provides the first reusable space transportation system for research, commercialization of space, and scientific exploration.

Meeting these great challenges has given us benefits far more valuable than our original investments. It has proven wrong those dreary souls who lacked the vision to support your efforts. With their pessimism, America could never have gotten off the ground. And with your space shuttle, we have again and again. And I'm convinced your success confirms a vision that we share: an America unafraid, reaching into space with courage and leadership, will be an America unsurpassed. We have it within our power to create a bounty of new jobs, technologies, and medical breakthroughs surpassing anything we've ever dreamed before or imagined.

We already benefit daily from a modern revolution in worldwide communications. We can communicate with each other at a moment's notice, virtually anywhere on the globe. We can anticipate tomorrow's weather and prepare for it. Our space shuttle system provides access to space for science, technology, communications, and national security.

Only a few weeks ago, we watched the Olympics on television, sharing excitement with people all over the world. I can remember—and believe me it doesn't seem long ago—when we lived in the horse-and-buggy days of television. We couldn't see a breaking event on the other side of the world until the film was shipped here. But, today, thanks to your research and development work, we have modern communications satellites beaming crystal-clear telecasts worldwide.

Another quiet revolution in technology has also been driven, in part, by the rigors of our space program. New materials from plentiful natural resources like carbon and silicon are taking the place of expensive metals in virtually all manufactured products. Our automobile engineers in Detroit are using lightweight, super-strong, plastic-like materials to reduce the weight of modern cars—and consumers are getting the benefits in the form of more miles to the gallon.

Computers using microchips are constantly redefining our world as they become smaller, more powerful, and less expensive. Those chips are the heart of inexpensive electronic calculators now commonplace in the workplace, community, and classroom.

Sometimes these technological changes take place so gracefully over time that we hardly notice them. Today our children have access to more computer power than most professional scientists and engineers had in their laboratories at the beginning of the space age.

Dr. Robert Jastrow, Chairman of the First NASA Lunar Exploration Committee, predicted nearly 2 years ago that the computer industry would double in size by 1986, becoming America's biggest business. Already, tens of thousands of practical applications of space and aeronautical technology are touching our lives. I've just seen an exhibit here with a vast array of new products from lifesaving vests for firemen to sophisticated aerial-scanning techniques to locate and identify everything from schools of fish to mineral deposits to healthy timberland.

In medicine we're seeing the vision of technology with a human face with one miraculous breakthrough after another. The procedure called CAT scanning uses a computer to compile a clear picture from x rays taken at different angles, often permitting patients to avoid the risks and discomforts of surgery. CAT scanning has come a lifesaver in detecting diseases of the brain and other vital organs.

The pioneer field of computer-controlled walking has given hope to thousands of paralyzed Americans that, someday, they may walk again.

The widespread use of sound waves allows doctors to avoid potentially harmful use of x rays. Using sound waves to monitor the progress of babies inside the womb permits earlier diagnosis of problems, a safer pregnancy and delivery for the mother, and better health for the baby.

HTS, for Human Tissue Stimulator, sends electrical impulses through wire leads to targeted nerve centers or particular areas of the brain, providing relief from pain and stopping unwanted involuntary motion. I'm happy to point out that HTS was sponsored by the Goddard Space Center.

I've also been shown a hand-held x ray machine and the Programmable Implantable Medication System, called PIMS, that administers medication automatically within the body.

It would be difficult to put a pricetag on the value of these human benefits. Even more dazzling opportunities lie ahead, if only we have the faith and courage to keep pushing on. Each technological breakthrough enables us to work from a new and higher plateau. It opens the door to great leaps in productivity which would have been considered unthinkable only a few decades ago.

Permit me to suggest that the fraternity of pessimists, who today insist strong growth will ignite high inflation, are looking at abstract statistics, theories, and models, not the reality of a changing world. They do not see that as we acquire more and more knowledge from new technologies, we no longer move forward in inches or feet; we begin to leap forward.

Working the zero-gravity environment of space, we can manufacture in just 1 month's time lifesaving medicines that it would take 30 years to manufacture on Earth. And we can manufacture crystals of exceptional purity that may enable us to produce super-computers and make even greater breakthroughs in productivity.

Our vision is not an impossible dream; it's a waking dream. As Americans, let us cultivate the art of seeing things invisible. Only by challenging the limits of growth will we have the strength and knowledge to make America a rocket of hope shooting to the stars.

High technology is born from capital, and more capital will require continued incentives for risktaking and investment, not tax increases, which would stifle growth. We support high-tech, not high taxes. The Federal Government must constantly endeavor to strengthen the private economy, while supporting research and development, particularly in universities, to train tomorrow's industrial and academic scientists and engineers.

Our agenda for excellence in education at the elementary and secondary school level is also crucial, so students, like those I met at Jefferson Junior High School on Monday, can acquire the knowledge to enter universities and, one day, step into these vital positions of leadership and responsibility.

Between 1981 and 1985, Federal investment in basic research will have increased by almost 30 percent in real terms. And we will carry forward that strong commitment into the future. We will also continue our support of tax credits for industrial R&D expenses, and we'll strive to lessen concerns that cooperative R&D between companies may violate antitrust statutes.

With the power of economic growth and the courage and determination of a free people, we can keep our number-one challenge in space—to develop a permanently manned space station, and do it within a decade. From that space station, we can carry out the kind of work in medicines and crystals I mentioned a moment ago; we can conduct new research, explore the distant planets, and, at the same time, unlock the vast potential for commerce in space by easing tax laws and regulations which discriminate against commercial ventures. And we'll be doing all these things for the sake of a more peaceful and prosperous world.

America has always been greatest when we dared to be great. We will be leaders in space, because the American people would rather reach for the stars than reach for excuses why we shouldn't. And as American technology transforms the great black night of space into a bright new world of opportunities, we can use that knowledge to create a new American opportunity society here at home. We can ensure every person

has not only an equal chance but a much greater chance to pursue the American dream.

To do this, we must maintain and increase our older industries' ability to compete in the world, stimulate creation of sunrise industries, and meet the challenge of ensuring American leadership and prosperity into the 21st century. Call me an optimist, but I'm convinced that if we do accept this challenge, if we maximize incentives, invest fully in the new technologies, and strive for the great breakthroughs in productivity, then, yes, we can outproduce, outcompete, and outsell the pants off anybody, anywhere in the world.

We can build an America that offers productive, secure job opportunities for all our fellow citizens, from assemblyline workers to research scientists in new industries such as biotechnology, robotics, and information processing.

We can meet our goal of assuring adequate supplies of affordable energy so that never again will the American people be held hostage by a foreign cartel.

We can apply new agricultural technologies to preserve our soil and environment, and dramatically enhance productivity through improvements in crop yields and resistance to disease and harsh environments. We can enhance our world leadership in agricultural production and in nutritional assistance to millions who look to America for hope and for help.

If we're to keep our economy healthy and strong, we need to stay healthy and strong ourselves. Our success will depend on each person's willingness to adopt healthy habits, our collective ability to improve an already effective health care system, and our continued research and pioneer work in the kinds of medical technologies you're developing right here. Before this decade is out, our administration is committed to reducing significantly the death rate for all age groups and to ensuring older Americans can live healthier, longer, and more productive lives. We can, and we must.

The dream of America is much more than who we are or what we do. It is, above all, what we will be. We must always be the new world; the world of discovery, the world that reveres the great truths of its past, but that looks forward with unending faith to the promise of the future. In my heart, I know we have that faith. The dream lives on. America will remain future's child, the golden hope for all mankind.

Thank you for welcoming me today. And thank you for all you do, and thank you for your courage to dream great dreams. God bless you all.

Mr. Beggs. Mr. President, if we may offer and present to you a small token of our appreciation for your coming here today. As you know, on the last shuttle mission, we went up and repaired a satellite. And that satellite—the Solar Maximum Mission Satellite—was developed here at Goddard, and indeed, the repairs were designed and developed here at Goddard. And they were installed with cooperation with the Houston Mission Control and the Houston astronauts, of course. It was a very successful mission, and we now have another very valuable scientific satellite working again for several years.

This model is a glass-blown model of that, showing the astronaut on his way out. And we hope that it will remind you many times, both of the visit to Goddard, as well as the strong support that you have given to this program and which we very much appreciate. And the encouragement which you continue to offer—we thank you for that very much.

Since the model is fragile, we'll deliver it to the Oval Office.

The President. Thank you very much. Thank you—thank you very much.

Mr. Beggs. What do you do up there without a horse? [*Laughter*]

The President. Thank you all very much. And now, as a little girl told me in a letter a few years ago—I'll get back to the office and go to work. [*Laughter*]

Thank you.

Note: The President spoke at 11:31 a.m. in the Center's Building 10. Prior to his remarks, he was given a tour of displays of space program work by James M. Beggs, Administrator of the National Aeronautics and Space Administration, and Noel Hinners, Director of the Goddard Space Flight Center.

Reproduced with permission of the copyright holder from Bylinsky, Gene. Space will be the next big construction site. Fortune, v. 99, Feb. 26, 1979: 63-65, 68.

SPACE WILL BE THE NEXT BIG CONSTRUCTION SITE

by GENE BYLINSKY

NASA plans to build an "antenna farm" that should transform communications here on earth. Satellites that tap the sun's energy could follow.

Man is a builder, ready to trek to the remotest corners of the earth for the profit and adventure of construction on a gigantic scale. Now, when the bold enterprises of corporations like Fluor, described in the preceding article, might be thought to have conquered the last frontiers, a new one is beckoning. For sheer drama, it may eclipse all the rest. If NASA has its way, the space near earth will soon begin to sprout all sorts of dreamlike structures, some of which are shown on the opposite page. Parasol-like antennae, some 100 feet across, will pop open in orbit to service an ever-expanding communications system back on earth—a system that will include pocket telephones not much bigger than Dick Tracy's wristwatch. Robot craft called "space spiders" will weave airy, fabulous structures out of materials little thicker than aluminum foil. Space-suited workers will be busy up there, too. In the near weightlessness of space even the scrawniest among them will be able to push around a structure that would weigh as much as a Mack truck on earth. Because these buildings will float in space, man will have the freedom to extend them in all directions at once—the dream of a small boy with an erector set come true.

This grand space show, duly publicized and televised by the space agency for the benefit of fascinated earthlings, will culminate at the turn of the century, or so NASA hopes, in the biggest space structures of them all: solar-power satellites. Each would be nearly as big as Manhattan, a startling twelve miles long and about three miles across. Shining like man-made stars at night, these giant platforms would beam energy to earth round the clock.

The first question that obviously comes to mind is: who needs these structures and who is going to pay for all the cosmic exhilaration? A single solar-power satellite, for instance, will cost somewhere between $2 billion and $20 billion, depending on whose estimate you believe, and the U.S. would have to have about 100 of them to supply 30 percent of its electric-power needs. The answer is that NASA's program is a mixture of the practical and the imaginatively farfetched. Some of the projects can be expected to pay their own way almost from the start, while others are too speculative for any meaningful cost-benefit analysis.

By 1983, NASA may be building the first simple structures in space with the aid of a beam-extruder to be carried aloft in the Shuttle's cargo bay. Solar panels will provide auxiliary power. The antenna farm at upper left is thought to be a viable commercial proposition, but debate still rages about the feasibility of solar-power satellites (upper right). As big as Manhattan Island, each of them would cost billions to build.

The practical, near-term projects will be in communications. Satellites that relay signals between points on earth are already a big and worthwhile business, and the first effect of the Space Shuttle will be to cut launching costs by more than half—from $20 million to $9 million. The cargo bay of the Shuttle will house a mechanical arm that can toss satellites out like basketballs—or reach out and retrieve them when they need repairs. As the communications traffic increases, the satellites will inevitably get larger and more powerful. The Air Force is already designing a dish antenna for radar that will collapse into a trim package for transport aboard the Shuttle and then pop open after it is launched.

The most useful space antennae are those in what is called geosynchronous orbit. This orbit, 22,500 miles up, keeps them above a given spot on earth and so always in a good position to receive and transmit signals. Many of the satellites launched in near-earth orbit by the Shuttle will be

Research associate: Alicia Hills Moore

equipped with rockets to take them on up to their stations. Later on, however, as communications needs continue to grow, it will be more efficient to build a great battery of antennae—an antenna "farm," as NASA calls it—in the near-earth orbit to which the Shuttle will be confined. The metal skeleton, perhaps 700 feet long, would house as many as thirty large dish antennae. Once completed, it could be towed or propelled up to geosynchronous orbit.

According to a study by Rockwell International, such an antenna farm could simultaneously satisfy many different communications needs. It could easily handle the rapidly growing volume of electronic mail, most of it generated by business. It could accommodate up to five nationwide television channels, though the viewers back on earth would have to buy a one-meter dish antenna at a cost of about $100. Because this transmitter in space would be much more powerful than those now in place, the receiving stations on earth could be simpler—as simple, in fact, as those pocket phones. An antenna farm could service as many as 45,000 private channels, which could handle calls from millions of pocket telephones. Rockwell estimates that the calls, which could also be made to and from conventional telephones, would cost only about 20 cents each. "We feel very confident about the technology we've designed," says C. L. Gould, an engineer who led the Rockwell study. "I think a company like ours could take a fixed-price contract to build the pocket telephone right now."

Rockwell also thinks that inexpensive satellite communication will be of great benefit to the underdeveloped world. Paramedics in remote villages would be able to get a diagnosis of difficult cases by pocket telephone and young people could be taught new skills by television.

It is in building the antenna farms that construction in space will really begin, probably around 1985. To get a jump on some of the problems, however, Grumman has already designed a beam extruder, a later model of which will be carried aboard the Shuttle (see the photograph on next page). It can turn out a triangular, interconnected skeleton of thin aluminum at a speed of five feet a minute. At that rate, the beam builder could cough up a mile-long structure in less than a day. There will be cherry-picker cranes equipped with their own maneuvering rockets, as well as more mundane space tools such as cable cutters, adjustable wrenches, pliers, and scissors. "You could go to any construction site and see equipment that might be schematically the same as we might use in space," says Allen J. Louviere, chief of the spacecraft-design division of NASA's Houston center. "You'd have to have workers, materials, trucks, an eleva-

tor, a crane. We've got to have all those, too, but they may look different and operate somewhat differently because of the unique conditions in space."

The main difference from conditions on earth—the virtual absence of gravity—is more advantage than problem. Structures won't have to bear the stresses they do on earth and will serve merely as a positioning framework for the mechanisms attached to them. "You don't have to worry about high winds, or a snowfall that might crush the roof," adds Richard L. Kline, deputy director of advanced space programs at Grumman. "The structure won't rust or corrode, either, the way my car does."

The biggest stress these structures will have to bear will be the thrust of the rockets used to move them up to geosynchronous orbit. Once they are 22,500 miles up and out from behind the earth's shadow, they will be bathed in continuous sunlight except for a few minutes of eclipse during the days of the spring and fall equinoxes. But the temperature change during an eclipse will be dramatic—as much as 700 degrees—and large expanses of thin metal would tend to curl around the edges. Other materials, such as a composite of graphite and epoxy, will hold up fine.

Weightlessness is not quite so congenial to humans. The orbital assembly men will have to have a grip on something solid. Otherwise, says Louviere of NASA, "if the thing you're trying to work on is bigger than you are, you may find that it's turning you, rather than you turning it." Spacesuited workers are rather clumsy, too, and tire easily, so a lot of mechanical aids will be used. A shirt-sleeved astronaut sitting in a flying robot with mechanical arms will be able to get a lot more work done. The astroworkers will have to be neat. Any debris will hang around their work sites to haunt them. If a workman drops a tool up there, it will not fall, of course, but slowly drift away.

As assembly moves farther out to the geosynchronous orbit where the solar-power satellites are supposed to be built, new hazards will loom. To shield themselves from periodic bursts of potentially fatal radiation from the sun, the astronauts would mostly work inside robot craft or control centers, directing mechanical arms and other automatic equipment. One of the first things Rockwell would like to see them build out there is the "Lunetta," a mirror perhaps a thousand feet in diameter. Clusters of these Lunettas would flash back as much sunlight as 200 to 300 moons, illuminating the streets of a city at night and saving energy on the ground. Rockwell thinks Lunettas could also be used to beam light to remote construction and exploration sites, such as Alaska's North Slope, and to augment the sunlight on croplands.

Solar-power satellites will be a grand climax to the space show—if they are ever built. Unlike earth-based solar collectors, these satellites would face no vagaries of weather or day-night cycles, and thus would be exposed to ten times the amount of sunlight available on earth. The thirty-six square miles of solar cells would feed ten megawatts of electricity into the antenna portion of the satellite, where it would be transformed into microwaves and beamed back to earth. Receiving antennae on the ground would turn the beam back into electricity, and put it into the power grid.

What would be an impressive construction job on earth becomes a mind-boggling one in space. NASA estimates that 550 workmen would be needed to build a solar satellite, and some space planners are already worrying about how to keep that many people healthy and happy in space. Each satellite would require 100,000 tons of materials, much of it exotic composites that now cost as much as $50 a pound.

continued

Ferrying up the people, equipment, and supplies would take ten flights a day by the Shuttle or its successor.

The job looks so formidable that some space boosters have seriously suggested using the moon rather than the earth as the main source of raw materials. Because the moon's gravitational pull is weaker than earth's, much less power would be needed to lift off large payloads. In this scheme, the moon's abundant and high-grade ores would be propelled for processing to space colonies in very high orbit or at the so-called Lagrange libration points, 250,000 miles from earth, where large structures would remain stationary because the gravitational pulls of the earth, the moon, and the sun are equalized there. The Rockwell report gave this plan rather cool treatment, but NASA is still studying it. Sunsat, an aerospace lobby, and L-5 clubs around the country (named for the fifth libration point) are keeping hope alive.

Apart from the cost of solar-power satellites, there are unresolved questions about just how safe those microwave beams would be for life here on earth. They would be carefully directed into the huge receiving antennae, and would in effect harmlessly defocus if a beam got "unlocked" from its antenna. But nearby areas would pick up a low-level dose, and nobody knows yet what long-term effect this would have on animals, plants, and man.

Advocates of the solar-power satellites point out that the beams would be only about one-fourth as intense as sunlight. Unlike sunlight, though, microwave radiation can be highly penetrating even at low intensity. Songbirds, which happen to be about the same size as the wavelength of the radiation, might almost resonate if caught in the beam. They would certainly absorb more microwave heat than humans.

"We need to know whether birds, bats, bees, and other species flying over the receiving antenna will be killed by the microwave beam," says Richard D. Phillips of Batelle Pacific Northwest Laboratories, who managed a study on the potential biological effects of the beam for the Department of Energy. "If the flying biota are killed, it may mean that the solar-power satellite concept, as now designed, is not feasible." Even if the beams are less dangerous than feared, says Phillips, the receiving antennae may have to be situated in remote, sparsely populated areas.

There are also unanswered questions about the beam's possible effect on the atmosphere—in terms of both heating it up and disrupting communications on earth. But the solar-power satellite holds such an enticing promise of unlimited energy that it at least deserves further study. Peter E. Glaser, a vice president at Arthur D. Little, Inc., who first proposed the idea ten years ago, suggests that if the U.S. finds the costs too much to bear, it might go into partnership with other countries. Glaser himself thinks that it would be irresponsible to commit the U.S. to the construction of solar-power satellites on the basis of current knowledge, but he also thinks that we should be spending at least as much on feasibility studies as we are on windmill research (currently $60 million a year). Other scientists would like to see us push ahead more rapidly, and one of them, Arthur Kantrowitz, who retired recently as chairman of Avco Everett Research Laboratory, has put his feelings in verse:

Arise, creators of worlds yet unimagined,
You have nothing to lose but your limits.

The decision rests ultimately with Congress, but whatever the exact level of funding, power from space, like power from fusion, isn't likely to arrive until the next century. Before the first crews take off to begin building the first commercial-scale satellite, space construction will have yielded major returns in transforming communications here on earth. ■

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Coming down to earth

Industry in space is a mirage of abundance.

Daniel Deudney, WORLDWATCH INSTITUTE.

by Daniel Deudney

No one looking at space a quarter century ago foresaw all ways in which space systems have altered human life, and no one today predicting space activities over the next 50 to 100 years is likely to predict all the uses to which satellites will be put. Yet enough is known about the potential of space and the needs of earth that some ideas—large-scale space colonies, solar power satellites and asteroid mining—can be eliminated as practical and desirable goals. A modest industry producing certain high-quality products is possible within this time horizon, but is unlikely to surpass the economic contribution of communications satellites. The longer-term prospects for human ventures in space are, of course, not knowable. But large-scale space industrialization is not a viable solution to the pressing population, energy or resource problems of the earth.

The success of the satellite-communications industry has spawned a great deal of speculation about the possibility of building industries in space. Experiments aboard the U.S. Skylab in 1974 revealed that the weightless, airless conditions of space enabled the production of certain goods that are impossible to manufacture on earth. Without gravity, crystals form much more regularly, permitting the creation of glasses and electrical devices that have vastly higher performance than any others. And the products can be formed without containers, eliminating impurities that are the major limit to the performance of certain optical and metallurgical products on earth.

The drug industry could be a major user of weightless space to achieve delicate separation of complex, nearly identical substances. A Johnson & Johnson subsidiary is working with the National Aeronautics and Space Administration (NASA) to conduct an extensive research program. Jesco von Puttakamer, a long-range planner at NASA, estimates that space manufacturing could lower the production cost of a drug that fights blood clots from its current $1,200 a dose to around $100, perhaps saving some of the 50,000 people who die of clots each year. Because cooling metals do not form convection currents in a vacuum, strong alloys can be made from metals that are grainy and crumble when combined on earth. Thus the German auto manufacturer BMW is reportedly interested in fashioning lead and aluminum alloy motor parts that would be highly heat resistant, self-lubricating and last for a half-million miles of use.

Expert opinion about the prospects for space manufacturing is sharply divided, reflecting the limited number of experiments that have been performed and the large uncertainties about the costs of setting up a commercially viable factory in space. The many experiments in materials processing scheduled for the shut-

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*Daniel Deudney is a senior researcher with Worldwatch Institute, an international research organization funded by the United Nations and various private foundations. This excerpt is drawn from Worldwatch Paper 50—*Space: The High Frontier in Perspective.

tle-launched Spacelab in 1983 will answer some questions, while undoubtedly creating even more. Because the most critical factor in the economics of space processing will be the weight of the raw materials and the processing equipment, the first markets are likely to be for products with a high value-to-weight ratio, such as pharmaceuticals and electronic devices, followed by specialty glasses and alloys. A study for NASA by Microgravity Research Associates estimates that two or three $500-million space factories, weighing 15,000 kilograms and serviced every three months by the space shuttle, could meet half the growth in demand in semiconductors in the United States over the next decade.

If these visions of space manufacturing materialize, the products will be quite expensive, limiting their use to markets such as advanced weapons systems, scientific instruments and medical devices where performance, not price, is critical. However, the most probable payoff from space materials experiments is likely to be new knowledge of how materials interact that can be applied in terrestrial manufacturing. The principal financial supporters of Spacelab, the West Germans, look to these experiments to augment their knowledge of basic materials science rather than as precursors to industrial manufacturing in space.

Although space manufacturing may become a modest industry some day, large-scale space industrialization is an unworkable attempt to escape from the problems of earth. Much of the recent writing about humanity's future in space has been dominated by a group of outlandish proposals for industrializing space—solar power satellites, space colonies and asteroid mining—that aim to bypass the earth's resource limits by importing energy and materials from space or exporting people from the planet. At first glance these massive undertakings have a certain logic: the

earth is limited, space is infinite. Outer space does contain vastly more energy, space, and materials than earth. Yet this abundance cannot be brought to bear meaningfully on the earth's problems. Based as they are on misleading ideas about the nature of humanity's earthbound resource predicament, attempts to realize these fantasies are likely to exacerbate the problems of the earth during a period of unprecedented environmental stress. Rather than signs of hope in a time of troubles they are the most grandiose hallucinations of technological civilization.

The plans for the large-scale habitation and exploitation of space have evoked extensive public enthusiasm, which reflects at least a growing realization that the present course of growth on earth cannot continue indefinitely. Long a staple of science fiction writers, space colonies were first seriously proposed in the early Seventies by Gerard O'Neill, a Princeton University physicist. In *The High Frontier: Human Colonies in Space*, O'Neill detailed plans to build colonies with at first 10,000 inhabitants, and later a million. Manufactured out of materials from the earth, and then the moon, the colonies would be completely self-sufficient by harnessing the sun for all sources of energy. Space colonization is specifically promoted as a solution to overcrowding and environmental degradation on the earth. By exporting even greater numbers of humans into these orbiting cities, the wildlife and wilderness qualities of the earth could be protected, he claimed, or perhaps even expanded.

Life there is envisioned as pastoral, pollution-free, pluralistic—sort of floating garden cities. "Artists' recreations" depict vast transparent domes with sunlight flowing in for plants and lighting. The reality of space habitation would be far bleaker for centuries to come. The radiation belts around the earth make these visions misleading to the point of fraud. Heavy thick metal shielding would be necessary to block the lethal quantities of cosmic and solar radiation. Life in space for the foreseeable future will be like that in a submarine, an offshore oil platform or an Antarctic mining camp—dangerous, cramped, isolated, and uneventful.

Large-scale space colonization is not now—and may never be—technologically feasible. Structures of the size envisioned are thousands of times larger than anything yet built in space. If the record of similar scale-ups on earth is any guide, there will be unforeseen and perhaps insurmountable problems. Ecologist Paul Ehrlich points out that scientists have no idea how to create large, stable ecosystems of the sort that would be needed to make space colonies self-sufficient. The key to such knowledge is, of course, much more study of the ecosystems on earth, many of which are becoming less diverse and less stable. It could be many decades before scientists know enough to understand, let alone recreate, ecosystems as complex as those now being degraded.

Nor are space colonies a meaningful response to the population and environmental problems of the earth. At a time when 800 million humans live in "absolute poverty" on earth, it makes little sense to think about building fabulously expensive habitats in space. Simply transporting the world's daily increase of about 200,000 people into space would consume the annual gross national product of the United States. And long before technology made space colonies feasible, the current rate of population growth would have caused the earth's life support systems to collapse. Human population growth is not an inevitable natural necessity requiring an ever more expensive technical response. Population stabilization is a difficult social challenge, but it is certainly less complex than the organizational and political skills needed for large-scale colonization of space. Even if feasible, the endless multiplication of human beings in these hive canisters is ultimately as pointless a vision as it is bleak.

> "Although space manufacturing may become a modest industry some day, large-scale space industrialization is an unworkable attempt to escape from the problems of earth."

The space resource venture given the most attention as having near-term relevance to humanity is the solar power satellite, or SUNSAT, envisioned first in 1968 by Dr. Peter Glazer. A solar power satellite system would consist of three parts: an orbiting array of photovoltaic cells to collect and turn sunlight into electricity, a microwave beamer to send the power through the earth's atmosphere, and fields of microwave antennae on earth to convert the beams back into usable electricity. Variant designs would use lasers in the place of microwaves, and mirrors in the place of photovoltaic cells. The system's principal appeal is its ability to collect virtually unlimited amounts of solar energy without obstruction from the atmosphere or the cycle of night and day and without polluting the earth's atmosphere with combustion by-products. During the Seventies, as energy costs rose and environmental constraints became increasingly visible, SUNSAT proponents, backed by large U.S. aerospace corporations, created considerable public and government interests

in the idea. They claimed that mass production of photovoltaic cells and new rockets many times the size of those in use today would make this scientifically feasible venture into one that was also technologically and economically viable.

The construction of SUNSAT would be an undertaking of unprecedented size and cost. A 1980 NASA and U.S. Department of Energy study estimated that 60 satellites, each as big as Manhattan Island, would be needed to produce 300 gigawatts of electricity, which is roughly the current U.S. usage. The cost estimates ranged from an optimistic $1.5 trillion to a more probable $3 trillion. If two SUNSATs were built each year, one heavy-lift rocket—seven times the size of the largest rocket ever built—would have to be launched each day for 30 years to build and service them.

After an initial burst of favorable press by space and energy groups, several in-depth studies of SUNSAT by panels of independent scientists and analysts concluded that the concept faced technical, economic, environmental and political hurdles that are probably insurmountable. The U.S. Office of Technology Assessment concluded that SUNSATs involved as many environmental risks as large-scale terrestrial energy systems such as coal and nuclear power—and more technological uncertainties. A 1981 study by the U.S. National Academy of Sciences went a step further, concluding that obstacles to solar power satellites were so great that no funds should be spent for its development for at least the next decade, a remarkable recom-

mendation for a group usually highly sympathetic to research.

The barriers to an economical SUNSAT are technological rather than scientific. At each step in its construction, technological barriers would have to be broken and costs would have to fall rapidly. Photovoltaic cells are now being made, for example, and there may soon be cheaper ones. But scientists do not know how to make cheap ones with the ability to withstand intense radiation and cosmic ray bombardment for decades. Similarly, many major advances and scale-ups in rocket design and the handling of materials are needed to build such large structures in space. One major uncertainty in the cost of SUNSAT is labor. Preliminary evidence suggests that workers could not stay in orbit at the construction site for more than a few days without absorbing unsafe levels of radiation. Unless the health of thousands of highly trained workers is to be sacrificed on this high-energy altar, work tours would have to be short, driving up training and transportation costs.

Even more troubling than these constraints are planetary-scale environmental risks. Beaming trillions of watts of microwaves through the atmosphere for extended periods of time is almost certain to alter the composition of gases in unpredictable ways. Launching millions of tons of material into orbit would also place large quantities of exhaust gases into the upper atmosphere, perhaps disrupting the thin bands of volatile gases, such as the ozone layers, that play important but poorly understood roles in regulating the habitability of the earth. An operational SUNSAT system big enough to make a difference in the terrestrial energy equation would be a shot-in-the dark experiment with the human race's one habitable environment—the earth's atmosphere.

The political and institutional barriers to SUNSAT are less quantifiable but no less intractable. These large satellites, powerful sources of electromagnetic radiation, would orbit in a relatively small band of near space that already carries a great deal of satellite traffic, so other uses of space would be constrained. At the minimum, international agreements would have to ensure that energy benefits reached those who would have to forgo other uses of these orbits. The operation of such a system would involve worldwide resource allocation regimes far beyond those now in existence. If these massive power systems ever fell into the hands of terrorists or politically ambitious generals, or fell back into the earth's atmosphere, the results could be disastrous.

One other mirage of abundance in space that has recently received attention is asteroids. A scheme to mine them to meet mineral needs on earth has also been proposed in some detail by former U.S. astronaut Brian O'Leary. These irregularly shaped rocks that orbit the sun, mainly between Mars and Jupiter, range in size from as small as a grain of sand to as big as the state of Texas. Although our direct knowledge of asteroids in space is limited, scientists have studied the composition of a few that have over the millennia collided with the earth. Many asteroids have nickel and iron contents several times as high as ores now mined and, unlike metallic ores on the earth, do not require energy-intensive smelting. Indeed, the world's largest and highest grade nickel deposit, in Sudbury, Ontario, is believed to be the remains of a giant asteroid that struck the planet over two billion years ago. Although there is probably enough metal in the asteroid belt to meet world needs for many centuries, getting the asteroids to the earth's surface would be costly and energy-intensive, and would risk an accidental collision and ecological disruption on a colossal scale. Long before it becomes feasible or economical to bring rare metals in from space, scientists should be able to turn the prodigiously abundant clay, silicon, aluminum, hydrocarbons and iron in the earth's crust into plastics, ceramics, specialty irons and glasses to meet global materials requirements. ■

FOR INDUSTRY IT'S ALMOST LIFT-OFF TIME

THE SHUTTLE'S SUCCESS AND CONGRESSIONAL SUPPORT SWEEP ASIDE SKEPTICISM

Just a few years ago, the idea of manufacturing products in floating factories orbiting 300 mi. above the earth seemed like so much pie in the sky. With the U.S. manned space program at a low ebb and the shuttle program plagued with delays, the efforts of the National Aeronautics & Space Administration to lure companies aloft were greeted with skepticism or with lukewarm interest at best.

But now industry is on the verge of embracing space. The shuttle is sailing from orbit to earth more easily than even its most ardent boosters predicted. And the Reagan Administration is encouraging NASA's plans to have a permanent space station in orbit as early as 1991. As a result, companies from Aluminum Co. of America to Western Electric Co. are beginning to view the heavens with an eye to their scientific and commercial possibilities. In fact, a recent NASA-funded survey turned up 84 companies interested in doing some 244 experimental and commercial projects in orbit.

The space agency has long nurtured a desire for a manned space station as a logical extension of the shuttle program. That project has been on the back burner, however, as NASA suffered through the years of budget cutbacks that followed the Apollo moon landing and labored under criticism of budget overruns on the shuttle.

SURPRISE MONEY. Now the mood has changed. Congressional support for a manned space station is so strong that both houses are forcing money on NASA. When the agency recently asked for $6 million for space station design studies, the House voted to add $10 million and the Senate $5 million. Says Representative Don Fuqua (D-Fla.), chairman of the House Committee on Science & Technology: "I had to restrain the subcommittee dealing with space."

With the shuttle ready to truck large components into space, NASA is raring to go. Building a permanent space station is "a piece of cake, compared with building the shuttle," says Robert F. Freitag, deputy director of the agency's Space Station Task Force. "There is nothing that we need to invent."

Preliminary plans call for a structure more than 200 ft. long and 100 ft. wide that will look like an odd collection of shiny cans flanked by huge arrays of solar cells. It will contain living quarters for four to six astronauts. Three or four pods will house laboratories. Space shuttles will dock periodically, bringing supplies, new crew members, and even entire room-size modules that can be "snapped" onto the station.

NASA figures it can put up such a space station at bargain-basement prices: a total cost of $7 billion to $10 billion. By comparison, it cost more than $16 billion to get the shuttle off the

ground, and the Apollo moon program cost $25 billion. NASA expects to have its first design for a manned space station in final form by mid-July. By September, 1984, detailed plans should be ready. NASA wants to award construction contracts by early 1986.

In all, NASA will spend about $40 million in the current fiscal year to develop a space station and promote its use. And the agency intends to ask the Administration to step up the level of spending when it considers fiscal 1985 budget requests in September. "I would like to see something in the order of $100 million in 1985," says NASA Administrator James M. Beggs.

HARD SELL. To get the money it needs, NASA has pulled out all the stops in an effort to muster support for the manned space station. It has launched a raft of feasibility studies and is hitting industry with a hard-sell campaign to persuade companies to gear up for space. NASA expects considerable help from a special Senior Interagency Group—including the Secretaries of State, Defense, and Commerce, the chairman of the Joint Chiefs of Staff, and other officials—that President Reagan has appointed to advise him on a space station program.

But the critical step for NASA will be getting industry on board. Agency officials believe that once industry has explored the merits of space, continued industrial involvement will follow. "We are going about our planning in a practical way," says Beggs. "Rather than design a space station and then try to figure out specific uses for it, we are taking the opposite tack: nailing down the needs of the users. We feel that the station architecture and design elements will evolve naturally from those needs."

To get its first input on just what the users may require, NASA last fall awarded eight aerospace companies contracts of $750,000 each to pinpoint just what U.S. industry would consider doing in space. Their report turned up companies interested in projects ranging from assembling giant communications satellites to developing new ways of processing materials and making drugs.

In addition, NASA is using consultants Booz, Allen & Hamilton Inc. and Coopers & Lybrand to proselytize 50 companies that are most likely to launch space ventures and collect information on their needs. Targeted are such companies as Du Pont, Eli Lilly, Mobil Oil, W. R. Grace, International Business Machines, and Hewlett-Packard. "Companies must be led into thinking space," says John J. Egan, who manages business planning at Coopers & Lybrand.

AT WORK IN SPACE

A modular space station (1) floats serenely 300 mi. above the earth. The 300-ft.-long structure with its wing-like solar cells and huge communications antenna will house scientists and work crews. Surrounding the station are unmanned platforms (2) for manufacturing or long-term experiments. Supplies and new crew members will be ferried up from earth by the shuttle (3). Astronauts will ride to the platforms in solar-powered tenders (4.)

Some critics charge that NASA has ulterior motives in its fervent efforts to involve industry. The agency's future depends on launching a long-lasting program that will have broad support. "They're looking for anybody who will support a space station," says one aerospace scientist.

MORE SATELLITES. So far, the communications industry has been NASA's biggest industrial customer. The space shuttle launched two communications satellites on its fifth flight last November, one for Satellite Business Systems and the other for Canada. More than 100 such satellites are booked for launch by the shuttle in the next seven years. The current industry push to start direct-broadcast satellite transmissions to homes will undoubtedly add even more communications satellites to the shuttle schedule.

But in the long run, NASA officials expect other commercial space ventures to dwarf the satellite launch service it now provides to industry. The agency has put together a smorgasbord of inducements to get cautious companies to take the first steps toward broader uses of space. On May 27, NASA announced that it will fly a shuttle mission in 1986 filled only with industrial experiments. Not only will the flight be free but NASA is also offering to kick in $100,000 toward the cost of approved experiments. "We call it our 10¢-off coupon," says John W. Cole, chairman of the commercial group

within NASA's Space Station Task Force.

The agency is also doing a brisk business with a "Getaway Special" program, which offers a budget research jaunt on the shuttle. For $10,000, NASA will launch a 5-cu.-ft. "garbage can" stuffed with experimental gear. And scientists can keep their work confidential. "Companies like it because we don't have to know everything that's going on in that can," says William K. Vardaman, NASA's manager of commercial applications.

The most ambitious program to date, however, allows companies to form exclusive joint ventures with NASA. Under the agreement, NASA takes responsibility for part of a company's project. NASA scientists may, for example, integrate experimental apparatus into the shuttle. Shuttle flights are free for as long as the work is in the research and development phase. When production begins, however, the free ride ends, and the company will have to pay for the flight, which can cost as much as $5 million for four to five working days on the shuttle.

PROMISING IN DEPTH. Nonetheless, the agency's efforts are attracting increasingly serious interest from industry. McDonnell Douglas Corp. and Ortho Pharmaceutical Corp. became NASA's first industrial partners more than three years ago. NASA expects more partners by the end of the summer.

Moreover, the McDonnell Douglas project, which uses a separation process called electrophoresis to manufacture drugs in space, is moving ahead at full speed. The companies first flew their apparatus on the shuttle in June, 1982, and four more flights are planned before the end of 1984. The experiments have shown that 700 times more biological proteins—such as hormones—can be gleaned from batches of cells in space than on earth. Based on those results, the company plans to launch a prototype manufacturing plant in 1985, with full-scale production starting on an orbiting platform in the late 1980s. "We could get into a positive cash-flow position within a few years after we start manufacturing," says James T. Rose, who heads the program.

One enterprising startup already has plans to base its entire business on space processing. Three-year-old Microgravity Research Associates (MRA) is the second company to form a joint R&D venture with NASA. The Coral Gables (Fla.) company hopes to produce semiconductor crystals in space. "It was becoming clear that the opportunities were coming to put these things together. The time was ripe for someone to get up there, and we decided to take a crack at it," says Richard L. Randolph, MRA's president and founder.

Several others are in the preliminary stages of setting up similar agreements. Fairchild Industries Inc. plans by 1986 to orbit small unmanned platforms that would stay permanently in space. Called Leasecraft, they would be rented to other companies for research and manufacturing. The platforms could be carried aloft and serviced by the shuttle. One company negotiating with Fairchild is McDonnell Douglas, which would use the platform for drug production.

Ball Aerospace Systems Div. of the Ball Corp. in Boulder, Colo., is negotiating with NASA to build a materials-processing lab to fit into the shuttle's cargo bay. Similarly, Teledyne Brown Engineering Co., of Huntsville, Ala., wants to build a general-purpose lab, also to be flown on the shuttle. "We could book customers now if we had the facility," says Lawrence R. Greenwood, deputy director of spacecraft systems at Ball.

COSTLY PAYOFF. The handful of companies with actual production plans for such facilities is in the vanguard. Space processing is expensive: Launch and recovery costs for apparatus and product exceed $5,000 per lb. At these freight costs, "you have to have a material that will sell for a very high figure per amount of weight" to make space processing worthwhile, says MRA's Randolph. So far, drugs and semiconductor materials are the only obvious candidates. Some advanced semiconductor materials such as gallium-arsenide can sell for as much as $50,000 per lb. And some pharmaceuticals can be worth up to $22 million per lb.

Many other companies are gearing up to use space as a lab. "The first thing space is offering us is an important opportunity to conduct research that we couldn't do on earth," says Paul E. Ritt, vice-president and director of research at GTE Laboratories Inc. in Waltham, Mass.

The lure of space to researchers and potential manufacturers is the near absence of gravity. By separating the effects of gravity from other forces such as viscosity and surface tension, scientists hope to be able to develop new or improved materials, including exotic crystals for advanced electronic devices, specialized alloys, and pharmaceuticals. "Any scientist would like to avail himself of the low-gravity environment," says David J. Larson, a staff scientist at Grumman Aerospace Research.

Manufacturers of advanced semiconductor crystals are among the most enthusiastic proponents of space research. Their goal is to use space to grow perfect versions of crystals such as gallium-arsenide that may replace silicon as the basis of the next generation of chips.

On earth the pull of gravity separates

components such as gallium and arsenic according to their densities and makes it hard to grow a uniform crystal. NASA's Vardaman compares the process to trying to make Jell-O with fruit in it—gravity pulls the fruit to the bottom. "In space you don't have that," he says, "so you can make a real good cup of Jell-O."

Other crystal defects are avoided in space because of the absence of convection caused by heating and cooling in the molten liquid from which crystals form. This stirring effect causes flaws in a crystal that in turn cause variations in the crystal's electronic properties. Such defects mean many finished semiconductor devices must be rejected.

Scientists at Grumman Aerospace Research are exploring the effects of gravity on the magnetic properties of crystals

Some 84 companies tell NASA they are interested in 244 experimental or commercial projects

used in detectors for the military. By applying the results of experiments done in space, the company has already improved some magnetic properties of earth-grown crystals by 50%. "The space material is the best we've ever produced," says Grumman's Larson.

Microgravity also makes it possible to process materials without having to hold them in containers. Molten metal, for example, becomes a spherical blob, and a tiny electric or magnetic field is enough to hold it in place. Johnson Matthey Inc. thinks this may provide a way to produce the iridium crucibles in which many semiconductor crystals are grown. Iridium is a temperamental metal with a melting point of 4,400°F. "It has a high chance of being contaminated while being melted, and if contaminated, it becomes brittle and difficult to work," says Laurence R. Thomas, Johnson Matthey's manager of technical services. **PURITY.** In space, contamination from contact with a container is eliminated, and the resulting iridium would be far purer than that produced on earth. One Johnson Matthey official estimates that high-purity iridium made in space would sell for $500 per oz. more than the material's present price of $1,000 per oz.

Many companies are investigating space research from the ground before committing themselves to large-scale efforts. "You can process candidate materials and weed some out before you go to the shuttle," says Michael B. Robinson, a staff scientist at NASA's Marshall Space Flight Center in Huntsville. Many are conducting experiments on rockets and high-altitude aircraft, where several seconds of weightlessness occur when the vehicle reaches the top of its trajectory. "This information provides direction and focus to our earthbound efforts," says Norman P. Lillybeck, manager of metal processing research at Deere & Co., which sent a furnace aloft to study carbon particles in cast iron.

Others are conducting experiments using a 340-ft.-tall "drop tower" at the Marshall facility. Du Pont used the tower to explore new ways of mixing materials to make catalysts. A furnace at the tower's top melts the material, which plummets earthward, solidifying in the 4.6 seconds of weightlessness of its fall.

In its effort to drum up interest from industry, NASA is getting some support from the Europeans and the Japanese, who are also eager to commercialize space. In Germany, for example, Messerschmitt-Bölkow-Blohm, as a private venture, has plans for free-flying platforms similar to Fairchild's Leasecraft. The company has already built a rudimentary free-flyer called SPAS that is due to be put into orbit by the next shuttle flight on June 18. The European Space Agency (ESA) is also planning a larger free-flier called EURECA, also to be built by MBB and launched by the shuttle. EURECA is scheduled for its first flight in April, 1987, and is to stay in orbit six months. **EUROPE AND JAPANESE.** Germany's Fried. Krupp has one of the most vigorous space programs under way. It is exploring the possibility of producing a magnetic alloy in space that would be virtually impossible to produce commercially in the earth's gravity. "This is definitely a candidate for eventual processing in space," says Jürgen Pötschke, who directs the program.

The National Space Development Agency of Japan is trying to push industry into more use of the U.S. shuttle. "We see improvements and innovations in the high-technology area if we can utilize the extraordinary conditions of space," explains Kazuo Matsumoto, director of the agency's space shuttle utilization department.

Although those efforts represent cooperation at this point, they may spell competition in the future. One German company official cautions that the Japanese may initially concentrate in specific fields and then move fast. Warns that official: "Europe has to watch out that it doesn't get run over from behind by the Japanese." Commenting on that observation, a NASA official who preferred anonymity added: "And the U.S. may get run over by both of them—using our own truck, the shuttle."

But if U.S. industry climbs on board the way NASA hopes, and if Congress backs the space platform program—as now appears likely—there seems to be little doubt that the U.S. will build the permanent presence in space that the shuttle promises. The shuttle, says Rose of McDonnell Douglas, "is a new transport system, and if you look back at the railroad and the airplane, you can see their effect on business and commerce. In several years the shuttle will seem like the original steam engine." And it is inevitable, he adds, that "space will be commercialized."

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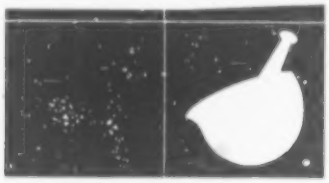
Why drugs will be made in space.
FDA Consumer, v. 17, Nov. 1983: 19-23.



Why Drugs Will Be Made In SPACE

by Donald C. McLearn

Sally Ride gained international fame this year as the first American woman in space; but aboard space shuttle Challenger she also tested a drug-making machine of tomorrow—one that promises to produce enough rare biological products in space orbit to bring relief to millions of patients here on Earth.

Following up on this experiment, a pharmaceutical company, in this decade, may set up branch plants in space to produce products like interferon, beta cells, and other materials now only available in small quantities.

For years scientists have known that cures for a number of diseases might be possible using certain cells, enzymes, hormones or proteins. But, while most of these materials are obtainable on Earth, the processes used to produce them are so limited by gravity that there's only enough made to conduct research. In space, away from the confines of gravity, it's possible to obtain these materials in great quantities and with the purity needed to treat diseases.

The space-age manufacturing technique, called continuous flow electrophoresis, separates materials in solution by subjecting them to an electrical field. The McDonnell Douglas Corp. of St. Louis developed the device and is in partnership with Ortho Pharmaceutical Corp., a division of Johnson and Johnson, New Brunswick, N.J., on the first product to be made. The National Aeronautics and Space Administration is providing the transportation and space scientists to run tests.

The in-space drug experiment has been given the acronym EOS, for Electrophoresis Operations in Space. The project was conceived six years ago. Tests of the device, using NASA's

space shuttle, began during the fourth shuttle mission in June 1982. A production unit could be in orbit by 1985.

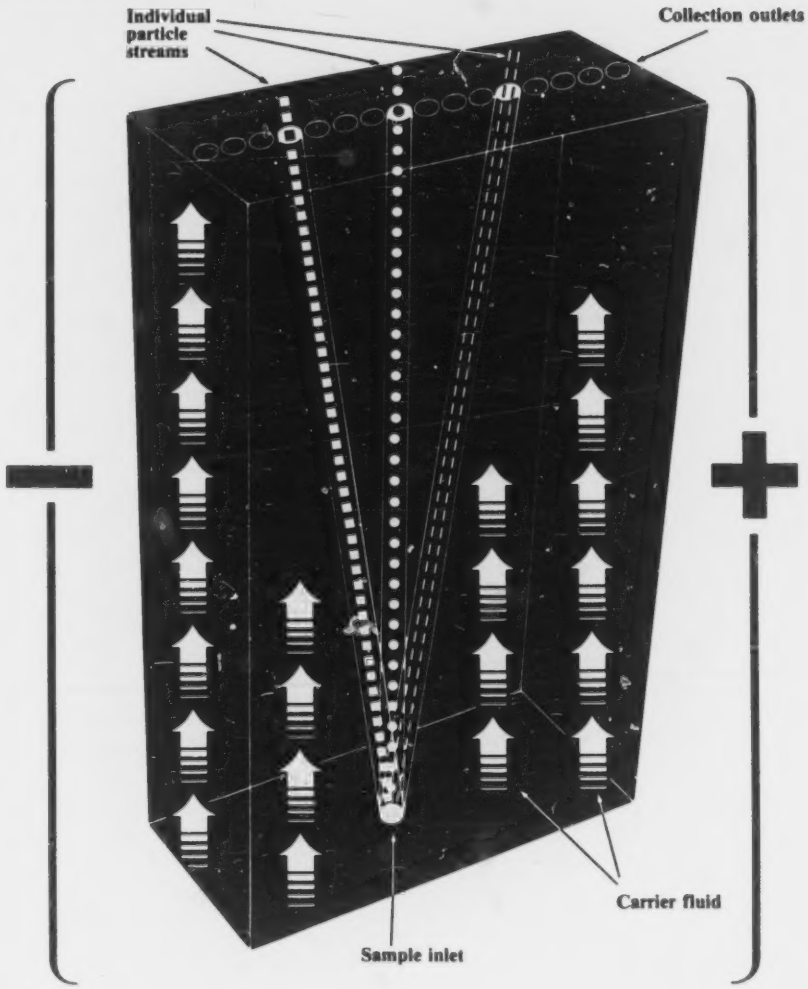
The basic electrophoresis process isn't really a new thing for lab scientists. It's been used for years in biology and medical laboratories to separate and analyze the components of such natural mixtures as blood serums and other protein mixtures.

The type of electrophoresis commonly used in labs is called static electrophoresis. It gets this name because the mixture to be separated (called the sample) is placed on a stationary object such as a porous gel plate. An electrical field is applied long enough to allow the differently charged particles to migrate to separate areas on the plate.

Although good separation is possible with static electrophoresis, only a small amount of sample can be separated at one time, usually about 0.01 milliliter. Hence, static electrophoresis is used for analysis and not for production.

Continuous flow electrophoresis is the process developed for the EOS project. In this process, a stream of sample material is continuously injected into a solution that carries the sample from the bottom of a long rectangular chamber to the top. As the sample flows through the chamber, an electrical field is applied across the flow. This causes the differently charged particles in the sample to move laterally at different rates, splitting the sample into distinct particle streams that exit through separate collection outlets at the top of the chamber.

In continuous flow electrophoresis, a sample of cells, enzymes, or other materials to be separated are injected into a fluid and carried— sans gravity—from the bottom to the top of a large rectangular chamber. As the sample moves through the chamber, an electrical field is applied across the flow. This causes the differently charged particles to separate and exit through separate collection outlets at the top of the chamber.



The continuous flow is the key to the process. Because the flow is steady, production is greatly increased.

However, in earthbound operations, production is severely limited by gravity. For the electrophoresis process to work properly, the sample must be light enough to flow with the carrier fluid in a steady, continuous stream. Because the sample fluid is generally much heavier than the carrier fluid, the sample must be highly diluted to flow properly. If the sample concentration is too high, gravity causes the sample stream to collapse around the inlet port and all is lost. Hence, in earthbound operations, lower concentrations of the sample are used to alleviate the gravity problem, hampering output.

The lack of gravity in space operations, on the other hand, allows greater concentrations of sample materials. The yield is thereby increased 100 to 400 times.

Gravity also causes uneven heating when the electrical field is applied across the electrophoresis chamber. This creates currents that make the particle streams waver back and forth, causing the streams to exit through the wrong collection outlets, seriously degrading purity.

Another gravity problem is "band-spreading." This phenomenon is the result of gravity acting on the slight density differences between the carrier fluid and the particle streams. Because the carrier fluid is lighter, gravity allows it to flow through the chamber more quickly, pulling the edges of the carrier stream faster than the center. This widens the stream and merges it with others, again jeopardizing the purity of the solutions collected.

Because of the heavier concentrations and fewer impurities, output on the first space shuttle was increased nearly 500 times over similar experiments on earth.

Of course, the experimental units used to date were only intended to verify the feasibility of operating the electrophoresis equipment in space. The small (580 pound) unit that Sally Ride used is not geared for commercial production.

A prototype production model is to be developed next. This unit, weighing 5,000 pounds, will have 24 times the capacity of the smaller unit. It will be flown in the bay of a 1985 shuttle. During the 1985 shuttle tests, scientists hope to obtain enough quantities of processed materials for Ortho Pharmaceuticals to begin clinical testing. Once the capabilities of the prototype production unit have been verified and FDA approval of the potential product has been granted, McDonnell Douglas plans to orbit a full-scale pharmaceutical manufacturing operation that would be serviced by NASA shuttle crews, who would collect the separated products and deliver raw materials. If all goes as planned, it will be there by the late 1980s.

What kind of material is being developed? Ortho Pharmaceutical is rather mum on that question. Company representatives claim they are protecting themselves against competitors and the possibility that the revelation will raise false hopes of "miracle cures." The firm acknowledges, however, that a number of biological products would be obvious candidates.

One would be interferon. Touted as a miracle drug, this substance seemed to be the answer to everyone's dream a few years ago. However, supplies made on Earth are limited and sometimes of low purity. Continuous flow electrophoresis machinery in space could solve such problems, but another procedure, biotechnological manufacturing with DNA manipulation, may be perfected before interferon gets into orbit.

Insulin-producing beta cells offer another good possibility. Beta cells, found in everyone's pancreas, produce insulin. Failure of insulin production leads to diabetes. Diabetes occurs when the million or so beta cells in the pancreas are damaged or destroyed. Diabetics must either inject insulin or take other drugs to keep their blood sugar levels normal.

Physicians have been experimenting with the use of beta cells for transplant surgery in diabetics, but testing has been hampered by a shortage of the cells. With the McDonnell Douglas electrophoresis device, the Washington University School of Medicine in St. Louis is stepping up its beta cell transplant research. Washington University and McDonnell Douglas are cooperating in space testing of samples taken from the pancreas of dogs to see if pure beta cells can be manufactured in space using electrophoresis.

Other potential products of the space drug plants include: growth-factor products for healing burns or surgical wounds; growth-hormone products used for pituitary gland problems such as dwarfism; antitrypsin products used for pulmonary diseases; and drugs used to thicken the blood for use in hemophiliacs.

While Ortho remains conservative about its objectives, McDonnell Douglas is publicizing each phase of the EOS project with great enthusiasm. Why not? The possibilities are out of this world.

Donald C. McLearn is a member of FDA's publications staff.

Have Rocket, Will Rent

Government policy has shifted in response to business eagerness to tap the vast potential of space.

By Del Marth

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QUEUES ARE FORMING at the nation's launching pads. Former astronauts, computer whiz kids, pharmaceutical researchers, geneticists, horticulturists, engineers—they are lining up with new rocketry and boxes of experiments, eager to cross the latest frontier.

"It is extraordinary how much money is going into new space industries," says Roger Selbert, a vice president of Security Pacific National Bank in Los Angeles. "We've had to add another vice president whose sole job is to handle inquiries from these new entrepreneurs."

President Reagan also sees the potential in the commercialization of space. In a directive issued in May, he said:

"Partnership between the U.S. private sector and the U.S. government will strengthen the U.S. space launch capability . . . contribute favorably to the U.S. economy and maintain U.S. leadership in space transportation."

No one agrees more than the private sector. But ever since the space age began some 20 years ago, hitching a ride has not been easy for business.

A major reason is that the U.S. government owns the launching pads and the tracking stations. It controls permits and licenses for space flights. It sets the price, and the schedule, for taking up commercial payloads.

The private sector, which helped create and refine the technology that made the United States pre-eminent in space, now wants part of the action. It will get it, according to the White House directive, because the government, like the private sector, sees the nation as a whole benefiting from the commercialization of space.

Key to the new policy is the ELV, the expendable launch vehicle—a rocket that cannot be used more than once. Before the advent of the re-usable space shuttle, all launches of payloads into space were achieved with ELVs like the Atlas, the Delta and the Titan. With the success of the space shuttle, the government planned to phase out ELVs later in this decade.

Under pressure from the private sector and because of increasing foreign competition in the payload-launching business, the government is now changing its mind. Not only does it see merit in using the ELV to handle commercial space experiments, but the National Aeronautics and Space Administration and the Defense Department have come to believe the ELV would make a fine backup for the shuttle.

There once was concern that the ELV would compete with the space shuttle. The shuttle does carry commercial payloads, particularly communications satellites, and NASA plans that it will continue doing so. But the shuttle's major mission remains government business.

Dismissing the concern over competition, Defense Under Secretary Herbert A. Reynolds told the House Subcommittee on Space Science and Technology:

"We are committed to the shuttle as the primary means for achieving access to space, and we do not believe the commercialization of ELVs will seriously affect the viability of the shuttle program."

He added that "the U.S. government must suppport and encourage the U.S. private sector to compete for the multimillion-dollar satellite payload and launch services market—or risk losing a portion of it to foreign competitors."

A project to stimulate that private-sector participation is under way.

"The time is right," says Kathryn

Little, director of development of the National Chamber Foundation in Washington, "to establish a unified industry position to encourage private commercial activity in space."

THE FOUNDATION is putting together a task force of 30 executives representing companies that have been—or want to be—active in space-related industries. Their assignment: compile a detailed, comprehensive package of recommendations on how to foster commercial development of space.

"These recommendations," says Little, "will be readily translatable into a legislative program." Issues to be covered include:

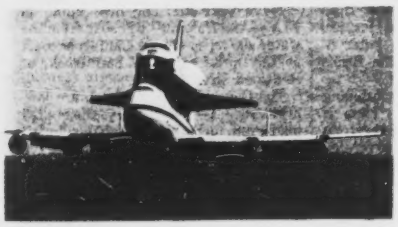

PHOTO: DAVID VALDEZ

The U.S. space shuttle, seen here atop a cargo plane, will remain "the primary means for achieving access to space," an official says.

- Ensuring open and competitive markets.
- Joint government/industry research and development.
- Designating a federal agency to oversee business ventures in space.
- International treaty obligations.
- New institutional arrangements to speed transfer of technology from government to business.
- Efficient commercialization of expendable launch vehicles.
- National security considerations related to private space activity.

The task force and its research activities will be supported by industry contributions. It is expected to take 12 months to put the package of recommendations together.

Little explains: "The companies that now have individual proposals before the government for commercial space activities face a largely unstructured bureaucratic environment, which is frustrating, time-consuming and expensive."

She says that a paramount concern of government officials is to avoid giving preferential treatment to particular companies and that a unified industry position will assure government decision makers that the task force proposals meet the business community's needs.

Five basic areas of commercial space activity are involved, says Gregg Fawkes, president of Pegasus Software, Inc., a computer software design firm in Washington, and the task force's principal researcher:

- Space transportation launch services, which include those firms now making ELVs or planning to build their own launch systems.
- Space materials processing, a fledgling industry using weightlessness in orbit to process silicon crystals, new and purer pharmaceutical drugs, and advanced alloys.
- Industrial research, which includes the study of processes in weightless conditions and the application of those research techniques on Earth.
- Communications, the largest of commercial space activities, which involves transmitting signals from fixed or orbiting satellites to Earth stations.
- Remote sensing, a field similar to the use of existing satellites to photograph and monitor the Earth's surface in search of natural resources.

Says Fawkes: "Our approach is quite different from other studies that have taken a look at potential space commercialization."

He notes that the NCF task force will be composed only of business people, representing a wide range of industries that might realize new growth opportunities in space. Many of the firms involved in the task force have not been active in space before.

"We will be addressing a very broad range of issues, from international treaties to government R&D policy," Fawkes continues. "This is necessary in order to establish a solid foundation for commercial activity in space."

The task force's recommendations will be very detailed, he says, since "general recommendations seldom get translated into action."

Fawkes says that Covington & Burling, a prestigious Washington law firm, "will be working with us to draft recommended language. So, for instance, if we find that treaty language needs to be amended to support private activity in space, we will propose some specific changes."

The NCF study will not try to "pick the winners" among countless new business opportunities in space. Rather, Fawkes says, the task force is concerned with making sure that an environment is created that will permit anyone who wants to explore new space applications to do so easily and efficiently.

"Space already provides many economic dividends and will do so on a much larger scale in the future," says Fawkes. "Space itself offers a whole new basis of scientific knowledge. And space applications drive a variety of other technologies—advanced communications, materials, energy cycles and robotics—that will be the basis of the next wave of economic expansion."

(Businesses interested in the work of the task force may write to Kathryn Little, Director of Development, National Chamber Foundation, 1615 H Street, N.W., Washington, D.C. 20062. Reports on the task force's progress will be released at frequent intervals, and the final report will be published in May, 1984.)

Commercialization of ELVs requires congressional approval of the continuing manufacture of the expendable rockets, which would be paid for and used by industry. The government would make available its launching facilities and equipment, at a price low enough to encourage their use.

The idea that the space shuttle could handle all space hauling for government and industry has been scrapped. Foreign competitors have successfully solicited U.S. corporations to send payloads up on the Ariane, an ELV launched from French Guiana by the European Space Agency. The agency is supported by both government and private funds from Western European nations.

ARIANE'S launch record to date has been spotty. Using an ELV similar to the Atlas, the European agency has sent up six rockets, but only four launchings have been successful. Nevertheless, the agency offers attractive rates for commercial payloads. Its marketing specialists in this country are convincing American firms that they can fly into space with the Ariane at a lower cost than on the shuttle, and on a precise schedule. The space shuttle has so far not managed to adhere to a precise schedule.

So aggressive has been the European agency that the Office of Technology Assessment, an advisory arm of Congress, reported last year that the United States was close to losing the lead in several critical areas.

OTA warned that the Europeans, and the Japanese as well, were taking a growing share of the market for satellite communications. Likewise, the report said, the U.S. lead in remote sens-

ing of the Earth's surface could be lost to the French by the middle of this decade. Also threatened was American pre-eminence in the processing of exotic metals and pharmaceuticals in space.

NOT SURPRISED that the foreign market is hustling American industry is William F. Rector, a vice president of General Dynamics. He estimates there will be a "need for launch services for approximately 245 commercial satellites between 1986 and 1995."

That represents, he says, more than $10 billion in potential launch vehicle revenue over the 10-year period. He points out that "schedule flexibility and reliability are ranked more important than launch costs by most commercial communications satellite users."

The United States is running less than a half-dozen shuttle flights a year and plans no more than 24 such flights annually in the 1990s.

James E. Beggs, NASA administrator, agrees with Rector that when "commercial launch requirements are considered in conjunction with planned Defense Department, NASA and other U.S. government missions, the demand exceeds the supply capability of the space shuttle in both the near and the far term."

The ballooning demand by business to get into space is particularly significant to Martin Marietta Aerospace. It manufactures the Titan, the granddaddy of ELVs. Discontinuing the Titan would cost "some 6,000 jobs for 220 suppliers in 25 states," says Peter B. Teets, general manager of the firm's space launch systems division.

But the economic effect of continuing the ELV system, not just the Titan, is even more wide-ranging, he says: "A proven lower-cost alternative to foreign space launch systems will reduce imports and contribute to our balance of trade. Likewise, the acknowledged U.S. leadership in space technology will be enhanced by commercial launch capabilities without burdening the federal budget."

He points out that these activities "directly translate into increases in high-technology jobs, with the usual multiplier effects on employment in other sectors of the country."

Some aggressive American entrepreneurs can't wait. While urging the U.S. government to embrace commercialization of space, they are building their own launch systems.

Space Services, Inc., of Houston, is one such firm. SSI, whose executive in charge of space flights is former astronaut Donald K. "Deke" Slayton, raised $6 million last year from foresighted Texans and launched its own rocket—the Conestoga I.

Next year another new name in ELVs—the Dolphin—will soar from the water 200 miles off the California coast as the initial effort of Starstruck, of Redwood City, Calif.

The Conestoga and Dolphin are low-orbit rockets—they carry their payloads into orbits 100 to 10,000 miles above Earth. Their launch pads are relatively inexpensive to build, at about $1 million, compared with launch facilities for a multistage Titan, at near $100 million. Titans and comparable rockets push sophisticated payloads, like communications satellites, into required higher orbits, the ideal being 22,300 miles, where satellites orbit at the same speed as Earth and thus remain above the same point constantly.

For the government to dismantle its ELV launching sites at Cape Canaveral in Florida and Vandenberg Air Force Base in California would be both wasteful and expensive, space experts now contend. The demand for ELV missions by industry, and as a backup for the space shuttle by the Defense Department, now seems clear.

BUSINESS IS aware that building its own launching facilities and ordering up a nonre-usable rocket like the Titan costs more per pound of payload than using the space shuttle—perhaps twice as much. But corporations that need high-orbit satellites are more concerned at present with getting aboard flights, and on schedule, than with initial cost.

Companies that need less expensive low-orbit payloads make up the market the new launch-system firms like SSI and Starstruck are going after.

They talk about using low-orbit satellites to prospect for minerals and oil, collect data on crops and forests and locate rail cars that railroads have lost track of. Texas oilmen foresee using low-orbit satellites to check on oil flow

The Shape of a New Space Policy

The Reagan administration is encouraging private sector participation in the space program, but the federal government will continue to play the dominant role for many years. The Reagan administration developed its partnership approach in announcing that the government "fully endorses and will facilitate commercial operations" of ELVs—expendable launch vehicles.

ELVs, the White House said, could help the United States "achieve routine, cost-effective access to space" while ensuring that the nation maintained "space transportation leadership."

Some elements of the new policy:

- The government will license, supervise and regulate American ELV operations "only to the extent required to meet its national and international obligations and to ensure public safety." On the other hand, commercial ELV operators must continue to comply with applicable laws and regulations—local, national and international—including security, safety and environmental requirements.
- The government will encourage the use of its own launch pads for commercial ELV operations. The government will have "priority use" of its facilities "to meet national security and critical mission requirements," although it will "make all reasonable efforts to minimize impacts on commercial operations."
- No government subsidies of private ELVs are contemplated, but the government "will price the use of its facilities, equipment and services consistent with the goal of encouraging viable commerical ELV launch activities."
- The government will encourage competition among ELV operators by providing "equitable treatment for all commercial launch operators" when government equipment and facilities are being sold or leased.
- If private operators wish to build their own launch facilities, they must submit their plans to the government for approval.

The White House directive emphasizes that despite the new policy of encouraging private ELV operations, the government "will continue to make the space shuttle available for all authorized users—domestic and foreign, commercial and governmental," with prices to remain stable through fiscal 1988.

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from their wells without having to send someone to read the meter.

If these small launch systems succeed and the government continues the ELV system in cooperation with industry, rockets carrying manufacturing and testing equipment will become commonplace. They will spawn a space traffic industry similar to the one that has grown around commercial airlines.

Orbital Systems Corporation, of Chicago, is an example of a new firm entering space commerce.

Three former Harvard graduate business school students—David Thomson, 29, Scott Webster, 30, and Bruce Ferguson, 28—undertook a study while at Harvard of how the government might encourage private investment in space operations. Their research prompted them to borrow funds and create the Chicago firm. Their product: a rocket to launch commercial satellites from the orbiting space shuttle into a higher orbit.

NASA has contracted with them to produce the rocket, convincing Thomson, the firm's president, that "space is the next commercial frontier."

SUCH VENTURES delight former Commerce Secretary Philip Klutznick. As head of a panel from the National Academy of Public Administration in Washington, he helped prepare a NASA-commissioned report on encouraging business ventures in space. His conclusion:

"The government must involve American companies in our space program if we are to justify the heavy investment the American people have made in the last quarter century."

Klutznick's panel recommended that the government make launch schedules predictable and reliable, grant full rights to inventions and proprietary information to private parties in joint endeavors and support private financing of space vehicles.

Congress listened in May to a parade of government officials and business leaders who unanimously supported the President's policy of sending Yankee ingenuity into space. Before the House is the Space Commerce Act, a bill to spell out guidelines for commercial exploration and to designate a government agency—the Defense Department, the Commerce Department or the Federal Aviation Administration—as the clearinghouse.

Says Space Services, Inc., Chairman David Hannah, Jr., a member of the National Chamber Foundation task force and the visionary behind the Conestoga rocket system in Texas: "There are going to be markets for space business that we haven't even guessed at."

To Hannah and other entrepreneurs, the upcoming encounter with space business is, like space itself, without limits. □

NASA's Next Mission

Big Business in Space

As it celebrates its 25th year, the agency is under pressure to shift its emphasis away from exploration and toward commercial and military uses of outer space.

By John Noble Wilford

WHEN THE COUNTDOWN NEARS THE final few minutes, a hush settles over Cape Canaveral. It is dark, a couple of hours after midnight on Aug. 30, and as if in response to some vestigial mammalian instinct, the senses grow more acute. The air smells of damp subtropical decay and, one imagines, sleeping alligators. I am peering across the lagoon out to the palmetto and to the sandy flats running to the Atlantic shore, three miles away, where the space shuttle Challenger stands on its truncated pyramid like a monument bathed in ceremonial light.

Its image shimmers in and out of focus. Sometimes in the dense, humid air the xenon-lighted Challenger looks like a mirage, which gives it a mythic aspect. We are looking and waiting for the greater light, the sudden dawn of ignition.

Waiting for the moment of launching, in the hushed atmosphere of anticipation, I never fail to sense something beyond sight and smell, something else — echoes. The echoes of the old days of space flight, the struggling days and glory days when we first became a spacefaring people.

Hard as it is for some of us to believe, on Oct. 1, the National Aeronautics and Space Administration will be marking the 25th anniversary of its creation, and so I am even more attuned to the echoes from the past. Over the years, I have seen 30 crews of astronauts embark on space voyages and dozens of tests of new rockets and launchings of craft to provide new communications links, survey the earth and the heavens and probe the planets.

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Back in the early days, waiting for liftoff was more often than not an exercise in futility. Some gizmo would balk at the last minute, and the launching would be scrubbed until another day, another week. Once, frustrated reporters were reduced to writing about the murder of a local cocktail waitress, calling it "the only successful shot fired here in weeks." Or the rocket would take off in the wrong direction and have to be destroyed in midair. People from those days still talk of a missile called Snark, which had the unhappy habit of taking off and plunging into the nearby Banana River so often that they began speaking of the Snark-infested waters.

In time, however, the countdowns usually went like clockwork and the destinations kept getting farther and farther away from the Banana River. It was no longer achievement enough just to get something in orbit. On the strength of the raw, gravity-defying power of the Saturn 5 rockets, whose rattling reverberations still echo in the mind, we reached the moon. Our automated surrogates ventured out to Mars, Jupiter, Saturn and beyond. We saw these worlds for the first time as worlds, not as baubles of reflected light in the sky. One of the spacecraft we bade farewell to at Cape Canaveral more than a decade ago, the hardy Pioneer 10, has cruised beyond the outermost planets, bound for interstellar space.

John Noble Wilford writes about space and science for The Times.

These were achievements to match the exuberant rhetoric of those early days. Reaching for a metaphor for the new experience in unfamiliar realms, President John F. Kennedy in 1962 spoke of space as "this new ocean" and of those who set sail on it as spacefarers embarking on "one of the great adventures of all time." This generation, he added, "does not intend to founder in the backwash of the coming age of space." The words breathed of romance and daring, of new frontiers to test the resolve of a people shaped by the experience of mastering frontiers.

T-minus-31 seconds and counting. Thirty-one seconds to go. The computers are running everything now. The thunderstorms have passed, the sky is opening up after a 17-minute rain delay, and everyone expects the launching to be flawless. Down the line. A piece of cake. Those fuel cells and auxiliary power units might send off a few alarms in the cockpit. Not to worry. A few heat-shielding tiles might fly loose during ascent. The shuttle will endure such things.

It is a tested machine. A fantastic flying machine, the astronauts say. The shuttles, the world's first re-usable spaceships, have been flying since April 1981. Part rocket, part spacecraft and part airplane, they represent an attempt to make travel on the new ocean more economical and more routine.

When development of the shuttles began in 1972, the nation had changed and so had its language of expectations. Another President, Richard M. Nixon, heeding the more constrained spirit of the time, had said: "With the entire future and the entire universe before us, we should not try to do everything at once. Our approach to space must be bold — but it must also be balanced." In the lean years that *(Continued on Page 50)*

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followed, throughout the 1970's, NASA struggled to build the shuttles on a shoestring, sacrificing the kinds of exploits that had so enlarged our sense of wonder. But the shuttles got built — two are now in service, Columbia and Challenger, and two more are under construction, with the possibility of a fifth being started — and in the early hours we wait for the eighth launching of one of these revolutionary spaceplanes.

The sudden dawn comes up at 2:32 A.M. — like thunder, Mr. Kipling, literally thunder. Orange flame lights up the sky for a few hundred miles, as if calling attention to the advanced state of American space technology. The explosions of energy shake the ground and reverberate through the humid night. New echoes. As the Challenger disappears out over the Atlantic, with its five astronauts, it climbs into an orbit of the earth carrying a communications-weather satellite for India, stamped envelopes for eventual sale by the Postal Service, an experiment in drug processing for industry and assorted other experiments.

The old echoes give way to a dawn of recognition. This is no adventure in exploration; this is a freight run.

Space flight is still no ordinary undertaking; it is fraught with risk, and never ceases to inspire awe. But more and more its character is changing. The era of space exploration, the time of finding out what is out there and learning to take the first steps in traversing this new ocean, the time of doing what can be done because it can be done, without economic constraints, has ended. We have demonstrated that we can sail the new ocean reasonably well, and, having done so, we tend to look upon the endeavor in less heroic terms. The familiar is less romantic. We have transformed some of our early visions into reality.

Now space is seen in more mundane, workaday terms as a place to be used and space flight as a means of exploiting this place — the new-ocean metaphor is no longer invoked — for commercial gain, military advantage and construction of orbiting outposts to handle the traffic in people and machines that is sure to follow. Footprints may be planted again on the moon and someday on Mars. A few craft will still go forth on missions of scientific discovery. But if current activities and proposals are an indication, the major thrust ahead is to incorporate space into the economic and political scheme of things on earth.

Thus, NASA finds itself in a critical time of transition as it begins its next 25 years as the institution primarily responsible for America's civil space program. The agency finds itself under increasing pressure to make space flight a paying commercial proposition in which private industry plays a larger role; to work more closely with the Defense Department, even at the risk of losing some of its independence and compromising its reputation for conducting an open program for all the world to share; to spin off some of its civilian operations to other Government branches; to maintain America's pre-eminence in space in the face of growing international competition, not just from the Soviet Union but from Western Europe and Japan, and somehow to establish for the nation a new vision of its future in space.

But the agency also finds itself preparing to meet a challenge of the kind it likes best, an ambitious engineering project at the forefront of technology. All signs indicate that the Reagan Administration is close to authorizing NASA to proceed toward its long-desired goal of assembling a permanent complex of laboratories, observatories, microgravity "factories" and living quarters in earth orbit — in short, a space station. Resonating through these grand plans are echoes from science fiction, echoes of the future.

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A new Presidential metaphor reflects current attitudes that shape what NASA can aspire to and what the nation's space program is likely to be for decades to come. On July 4, 1982, President Reagan was welcoming home the crew of Columbia's fourth and final test flight. Standing in the desert sun at Edwards Air Force Base in California, he said: "The fourth landing of the Columbia is the historical equivalent to the driving of the golden spike which completed the first transcontinental railroad. It marks our entrance into a new era. The test flights are over, the groundwork has been laid, and now we will move forward to capitalize on the tremendous potential offered by the ultimate frontier of space."

The metaphor is no doubt apt, or will be made so by the vigorous efforts of the Reagan Administration and NASA's leadership. True to their official name, the Space Transportation System, the shuttles and ancillary equipment are to be the transcontinental railroad of the space age, a vital link between earth and a region considered to be ripe for a multitude of uses and, perhaps, someday, for human occupation. Just as regular railroad service helped open up the American West, regular shuttle service could open up space to human activities on an extraordinary scale — the establishment, as the President said, of "a more permanent presence in space." From four flights this year, the shuttle traffic could escalate to 11 flights next year and 20 a year by the end of the decade.

On the same occasion, the White House released a summary statement of the Administration's space policy. Heading the list of "basic goals" was one to strengthen the nation's security through space. But more emphasis than ever before was placed on efforts to obtain economic benefits "through the exploitation of space" and to "ex-

pand United States private investment and involvement in civil space and space-related activities." Science and exploration were mentioned, though hardly emphasized.

These words about economics produce the echoes to which NASA nowadays responds. The business of the space enterprise will become more and more business. A few days before the Challenger's launching, Lieut. Gen. James A. Abrahamson, NASA's shuttle chief, said: "We're moving into a time when space is going to become much more of a commercial endeavor, is going to become a place where we'll be doing many more things that will have applications to people on earth. I see it as a time when businessmen around the world are finding that commercial space enterprises are well worth the risk and offer a real potential for profit."

This is not merely a reflection of the influences from a business-oriented Republican

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Administration. Some of the first tentative steps toward exploring commercial prospects in space were taken by the Carter Administration. It was perhaps inevitable, given the nature of people and their approach to new frontiers, that after the period of exploration there would follow a period devoted to possible exploitation. First, we went out to space, and now, in a sense, we are trying to embrace it and bring space down to earth. We may be left for a time with only the echoes of the testing and exploring times, but — with a sigh, perhaps — we must accept the fact that the American civil space program is growing to maturity. It has passed through the joys and crises of precocious childhood and now is being called upon to do grown-up things, like earn a living and establish permanent roots in space.

The leaders of NASA are striving to reshape the agency to respond to the railroad metaphor and also maintain the can-do fervor that has motivated its best engineers and managers. It is not an easy task. If the agency does not get into step with the new economic and political realities, especially regarding its relations with industry and the military, it could wind up on the periphery of the space enterprise it did so much to mobilize. Already, the Defense Department's space operations have surpassed NASA's in annual spending — $8.5 billion, compared with NASA's $7 billion — and the Reagan Administration plans to increase military space spending by more than 10 percent a year over the next five years, a greater rate of increase than for the rest of the department. The Commerce Department's National Oceanic and Atmospheric Administration has assumed the operations of weather and earth-resource survey satellites. And years ago, in the first and as yet only profitable commercialization of space, private industry took over communications satellites.

If, on the other hand, the agency does not continue to have challenging goals, it could lose many of its best engineers and managers. NASA is already much smaller than in the Apollo days, with a work force of 21,000 compared with 36,000 in 1968. Many of the brightest engineers, attracted to NASA during the Apollo Project, now hold critical middle-level management positions; without new challenges, they would be tempted to leave. There are signs that the "brain drain" is beginning.

By background, today's NASA leaders seem suited to the new era of exploitation. Unlike previous administrators — two university presidents, a lawyer-politician, an engineer and a physicist — the present NASA administrator, James M. Beggs, is a former business executive. He was the executive vice president of General Dynamics Corporation just prior to taking the job in 1981, but before that had held management posts at NASA and the Department of Transportation. The deputy administrator, Hans Mark, is a former Secretary of the Air Force. The associate administrator for space flight, who runs the shuttle program, is General Abrahamson; he had overseen the F-16 jet-fighter development. Though there have been businessmen and generals in NASA's management before, now they seem to be there with the mission of establishing stronger ties with business and the military.

When Mr. Beggs took over, he set himself one major long-range goal: to win approval for NASA to embark on the space-station project. In announcing preliminary plans for the station this summer, Mr. Beggs said: "It will open up commercial opportunities we have not dreamed of; it should improve our national security; provide more sophisticated science, and be a source of international cooperation. If the United States does not take this step, we will lose our pre-eminence in space." That is, the station was to be the centerpiece in NASA's response to Administration pressures for economic and military exploitation of space — as well as to the agency's own institutional momentum. Such an under-

taking would keep NASA where its engineers like to be, doing the big project.

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Anyone who saw the movie "2001: A Space Odyssey" has a notion of what an orbiting space station could be like: a huge white-spoked toroid slowly revolving in the great beyond, inhabited by astronauts and engineers who operate instruments of high technology and dispatch craft to the more distant reaches of space. A space station was high on NASA's post-Apollo planning agenda, but nothing came of it except the experimental Skylab, operated in 1973-74. Plans for a more ambitious station had to be set aside in favor of the shuttle, which NASA engineers accepted because they had to, budgets being what they were, and also because they envisioned it as the ferry that would someday shuttle back and forth between earth and the space station.

The White House is expected to make a decision on the space station very soon, perhaps early enough so that NASA, if the decision is favorable, could get some start-up money in next year's budget. But NASA's immediate plans are more modest than the 2001 station. According to a NASA task-force study, the core of the station would be a large cylindrical "house," where four to six astronauts, engineers and scientists would live, conduct their work and operate the rest of the station.

This habitat would be equipped with ports into which the shuttles would dock. Attached to the habitat would be additional chambers for prototype orbital factories — places for processing metal alloys, crystals for electronics, drugs, vaccines and other industrial products that presumably could be made better, or only, in the microgravity vacuum of space.

Extending out from the habitat, at the end of long girders, could be the antennas, solar-power panels and other modules containing experiments. Another platform for experiments, uninhabited, could fly nearby so that it could be serviced by the astronauts and yet be free from the vibrations and contaminations of the main station. If development were to begin next year, Mr. Beggs said, the basic elements of the station could be aloft by 1991 at a cost of $9 billion.

Later, the station could be added to, module by module, beam by beam, much like a Tinkertoy set, until it accommodated from 12 to 18 people and spread out like an orbital industrial park and service station for refueling and overhauling satellites and interorbital tugs. A second space station, probably uninhabited, might also be placed in a polar orbit for earth sensing and for military reconnaissance and command operations. So far, however, the Pentagon has been cool to NASA's space-station plans. It is supporting NASA but says it has not identified a single military job that could be done better by a space station than by conventional spacecraft. In time, more active Pentagon backing may be vital to the project, as it was in winning continued financial support for the shuttle.

By 1991, the Soviet Union will probably have its own large space station in orbit. For the last decade, Soviet efforts have focused on flights of its small Salyut stations, each of which has remained in orbit several years and served as home for crews for as much as six months at a time. The Salyut 7, now in orbit, was doubled in size last June by the addition of a module, and at the time, Soviet officials reiterated their goal of creating "long-lasting, manned orbiting space stations."

But NASA officials are not stressing Soviet competition so much as the prospects of inaugurating an extraterrestrial industrial revolution through the space station and other programs. "No longer is it a question of whether space has commercial promise," said Mr. Beggs, "but rather how best to proceed to maximize that promise for national economic well-being. I think that is a very significant point in the history of this agency and the history of this nation."

In keeping with the Administration's goal of getting private investors more involved in space, NASA announced recently that a 1986 shuttle mission would be devoted entirely to industrial experiments. A NASA-funded study found that 84 companies were interested in doing 244 experimental and commercial projects in orbit. The first working example, which has already been on four shuttle missions, was a separation process known as electrophoresis. Developed by the McDonnell Douglas Corporation in conjunction with Johnson & Johnson, it successfully tested methods of making ultrapure pharmaceutical products, such as vaccines and a possible replacement for insulin.

For the first time, moreover, private companies are putting venture capital into space flight other than satellite communications. Fairchild Industries plans to build its own small unmanned orbital platforms, to be deployed by the shuttle, and to rent space to other companies for research and manufacturing. A West German company, Messerschmitt-Bolkow-Blohm, has already built a similar craft. A group of Texas investors is testing a private space-launching rocket. Three young graduates of the Harvard Business School recently set up their own company, Orbital Systems Corporation, and received from NASA exclusive rights to develop and market a propulsion system for launching satellites from the shuttle. And several large companies are interested in the Reagan Administration's plan to allow private industry to buy Delta, Atlas and Titan rockets and launch them for hire.

A standard arrangement to get private industry thinking space is an exclusive joint-endeavor agreement between NASA and a company with an idea that has commercial potential. The agency offers the company a free ride on the shuttle for as long as its work is in the research-and-developmental stage. Three companies have signed such deals and several dozen others have expressed interest. When the manufacturing process reaches a production stage, the company begins paying a hauling fee, which could be as much as $5 million for each shuttle flight. Shuttle fees run about $42 million for a payload that takes up the full cargo bay. A customer can reserve the entire 60-foot-long bay or part of it, and pay accordingly. These fees are expected to increase substantially in 1985 to reflect the true costs of the shuttle flights.

Other arrangements are being negotiated on a case-by-case basis. Such high-risk research-and-development ventures also enjoy substantial tax deductions for the investors. There have been some exploratory talks about having a private company pay for an additional shuttle in return for an arrangement with NASA to be the shuttle marketing agent.

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There are, of course, critics and skeptics of the new plan for NASA. They fear that NASA may be overselling the prospects for significant commercialization. NASA, they feel, lacks sufficient assurance of funding to carry out the projects that are envisioned as justifications for the space station. At the same time, it wants to jump into another big engineering endeavor that could, as with the shuttle in the 1970's, wreck chances for a more balanced program of science exploration and commercial activities.

They also believe the Reagan Administration is being hasty in its moves to turn over some segments of space activities to private industry. A recent study by the National Academy of Public Administration, composed of 294 scholars and Government administrators, recommended against a transfer any time soon of the space shuttles to full operation by a private company.

A proposal by the Reagan Administration to hand over to private industry all weather satellites and the Landsat earth-resource survey satellites, now operated by the National Oceanic and Atmospheric Administration (after they were developed and tested by NASA), has run into heavy opposition in Congress. Critics charge that, in the case of the weather satellites, the Government would be setting up a private monopoly whose sole customer would be the Government itself. They say the Landsat divestiture makes even less sense. According to a study prepared under Government contract by Earth Satellite Corporation and Abt Associates, an organization of research and development consultants, only substantial subsidies and Government-guaranteed data purchases could produce a profit for a private earth-resource survey company for many years to come.

Some projected commercial uses of space are the processing of metal alloys, crystals for electronics, and drugs and vaccines.

A source of deeper concern is the shuttle itself. As successful as the flights have been, it remains to be seen whether the shuttles can live up economically to their advance billing. In the original projections, the four-shuttle fleet was expected to fly 560 missions over a 12-year period, with each vehicle being able to land, be serviced and take off again in two weeks. This was a totally unrealistic prediction, it turns out, conceived in part to justify the shuttle to Congress and the public. The more often the shuttles flew, the less each flight should cost — a matter of overhead divided by volume. "That was the phoniest Mickey Mouse economic analysis that ever went on record," said Richard D. DeLauer, Under Secretary of Defense for Research and Engineering.

Shuttle officials have long since abandoned predictions of two-week turnarounds. Their present goal is a total of 24 launchings a year by 1988 for the fleet of four shuttles, 30 by 1990 and 40 by 1992. A recent study by the National Research Council concluded that the chances of reaching 30 launchings by 1990 were "impossible or highly improbable" because of engine-maintenance and refurbishment problems. Still, General Abrahamson foresees a "crossover point" in shuttle launching-rate economics around 1988. He said that with a higher launching rate, higher customer fees based on realistic costs and more efficient operations, the "loss-leader part of the program" should then be behind NASA.

Unless the shuttles pull out of the red and can produce annual revenues of at least $2 billion, as Mr. Beggs has forecast, NASA may be hard put to support a more aggressive program in the future. Although NASA has received modest budget increases in recent years, to pull out of its 1970's doldrums, its current annual budget of $7 billion has less than 40 percent of the purchasing power of its allocation in 1966, the high point of the Apollo mobilization, when there was enough money not only for going to the moon but also for initiating the spectacular planetary expeditions. Skeptics, particularly scientists, say from bitter experience that if anything has to go to finance the space station, it will likely be NASA's science programs.

NASA will be making its push for accelerated space-station funding at the same time it is supposed to be reviving its planetary exploration program. After a lapse of six years, in which no major new planetary missions were authorized, the Administration this year finally approved a program to send a spacecraft to map cloud-shrouded Venus by radar in 1988. On the drawing boards are missions in the 1990's to orbit Mars to study the planet's geology and climate, to visit the vicinity of a comet and asteroid, and to probe and map Titan, the large satellite of Saturn. Other proposals include missions to bring back samples of Martian soil, collect fragments of a comet and to orbit the moon to prospect its resources for exploitation.

Under a plan developed earlier this year by a committee of leading scientists, such expeditions could be supported with an investment of $300 million a year over the next two decades, less than 5 percent of NASA's budget. That would be half again as much as planetary exploration's current budget, but considerably less than spending a decade ago. Reaction to the plan has been favorable at both NASA and the White House.

Not to have a commitment to future missions would be to turn away from one of the most exciting enterprises of our time — our voyages of discovery in the solar system. Shuttles and space stations may expand human activities in space, but the little craft that visit other worlds with their cameras and inquiring sensors expand our knowledge and inspire a sense of wonder about our place in the universe. While the shuttles make their increasingly routine freight runs in the years to come, Voyager 2 will be flying by Uranus and out to Neptune, and the orbiting space telescope, scheduled to go into operation in 1986, will be extending our vision of the universe.

Scientists have also noted that NASA's budget crunch during the shuttle buildup cost dearly in missed opportunities. A "grand tour" of the planets, with craft far more sophisticated than the Voyagers, was canceled. The United States pulled out of an expedition, with the European Space Agency, to orbit the poles of the sun. No American satellite will be going out to rendezvous with Halley's comet in 1985-86, as had been proposed, leaving such explorations to Europe, Japan and the Soviet Union. Even the shuttle suffered. The original plan, abandoned because of costs, was to make it a completely re-usable vehicle, and thus more economical to operate, instead of having to replace its booster rockets for each launching, which is now the case.

NASA's leaders have sought to reassure scientists of their commitment to scientific exploration in the space-station era. They note, for example, that the station would

Unless the shuttles pull out of the red and can produce annual revenues of at least $2 billion, NASA may be hard put to support a more aggressive program in the future.

be a key element in the mission to obtain samples of Martian rock. The samples might be returned there to be processed so that Martian microorganisms, if any exist, would not contaminate Earth. The station could also be a port of embarkation for manned flights back to the moon or to Mars. "If such a base were in orbit by the year 1991," wrote Mr. Beggs in the journal Spectrum, "the United States would be back on its way to the moon by the year 2000."

Out of this time of transition for NASA, for all the emphasis on the practical aspects of exploiting space, may emerge a larger vision of what America should aspire to in space. We can now contemplate greater aims because we have the technology, thanks in large part to Apollo in the 1960's and the shuttle development in the 1970's.

George A. Keyworth 2d, President Reagan's science adviser, went to Washington two years ago with discouraging words for NASA's ideas about big ventures. But he has changed his mind. Mr. Keyworth has decided it is time to return to a bolder approach to the space program and to "inject a new sense of vision into U.S. space exploration." Space, he says, is "a place to be careful, but not to be timid." Some of the less-timid initiatives he has in mind include the development of shuttlelike vehicles to fly from the space station, which he sees as eventually becoming a transportation hub, the development of colonies on the moon and the launching of astronauts from the space station to Mars.

These words sound like echoes from the glory days earlier in NASA's first 25 years. Whether the spirit of Apollo can ever be rekindled is questionable. NASA no longer has the political clout it had then, and the nation is probably in no mood for what might seem to be technological extravagance. But we are a spacefaring people now — our travels have only begun. ■

PATRICIA E. HUMPHLETT

PROPOSED SALE OF LANDSAT AND THE WEATHER SATELLITES

Reproduced from Humphlett, Patricia E. Proposed sale of Landsat and the weather satellites. Congressional Research Service Review, v. 4, Oct. 1983: 12-14.

On March 8, 1983, President Reagan announced that he supported transferring to the private sector all U.S. civil remote sensing satellites including Landsat, the weather satellites, and future ocean sensing satellites. While an endorsement of the transfer of Landsat had been expected, the inclusion of weather satellites in the announcement took the user community by surprise and raised a storm of controversy. Users of weather satellite data were concerned that they would lose access to it or have to pay for what the Government now disseminates for free.

In Congress, some Members were concerned that the Administration would transfer the satellites without their approval and introduced legislation to require congressional approval of any sale or transfer of remote sensing satellites. The Administration has since indicated that it has no intention of acting without the advice and consent of Congress.

Despite that assurance, some Members and some user groups continue to raise questions about the private sector's ability to provide system continuity, to meet national security requirements, and to operate the system without increasing Government and user costs. The Administration expects to answer these and other questions through a request for proposals (RFP), which the Department of Commerce will issue to industry in late November.

Landsat is a remote sensing satellite that returns data which can be processed into images or digital data for use in geology, agriculture and other areas.

Landsat was developed by the National Aeronautics and Space Administration as an experimental program, and, although the program was a technical success, no long-range plans were made to convert it to a more user-sensitive operational system. The lack of Government commitment to long-range plans has surpressed a Landsat data market and data sales do not meet procurement and operations costs. The Landsat system costs (on average) $75-$100 million a year to build and about $50 million to operate. Federal and non-Federal data purchases, although difficult to estimate, average less than $20 million per year—a net loss of $100-$125 million annually.

In 1979, seven years after the first Landsat began returning data, President Carter transferred Landsat operations to the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce. At the same time, he requested NOAA to study whether the private sector could operate a land remote sensing system in the future.

The Carter administration planned to build and launch Landsat 4 and three follow-on satellites to continue Landsat as a Federal program through 1994. It was thought that a Government commitment was necessary to encourage private sector investment in data interpretation equipment, training, and long-range studies, and thus to increase the data market. The Carter administration hoped that Landsat data sales would be large enough by 1994 to meet satellite procurement and operations costs, and that the private sector would then be able to operate the system for profit.

The Reagan administration also wants to transfer Landsat to the private sector, but trimmed six years off the Carter schedule. The Reagan administration currently plans to fund only one more satellite to be launched after Landsat 4 fails. Landsat 4 is failing prematurely, but Landsat 5 is expected to last three years, continuing the Landsat program through 1987. According to the Administration, the private sector is better equipped than the Government to expand the Landsat data market; the private sector has the profit incentive and experience in marketing new products.

Furthermore, the Reagan administration supports the view that the Government should not produce goods or services where the private sector can provide them more cheaply and efficiently. A potential problem with this plan is that, if the private sector does not take over Landsat, the program will end in 1987. Furthermore, since it takes four years to build a Landsat, even if the Government decides to stay in the program, there will probably be a gap between satellites; a private firm would also have a problem delivering a satellite without a data gap.

President Reagan endorsed the commercialization of the weather satellites as well as Landsat. Again, this policy is based on the view that the Government should not compete with the private sector if the private sector is capable of providing the same services. According to Secretary of Commerce Baldrige, the commercialization policy decision included the weather satellites because of the economic risks involved in a private sector Landsat operation; weather satellites, with an established user market, can provide the revenue base that a private operator needs to develop a Landsat market.

The Reagan administration also hopes that a combined Landsat and weather satellite operation will provide better data at a lower cost. Currently, the Communications Satellite Corp. (COMSAT) is the only firm that has proposed commercializing both Landsat and the weather satelliites. It is unclear whether enough other firms will be interested to ensure a competitive bidding process on the satellites. In addition, once the satellites are transferred to the private sector, it will be difficult for another firm to enter the market, thus creating a monopoly. Critics have questioned whether such a monopoly would have the incentive to develop the Landsat data market or would be in the Nation's best interest.

The Reagan Administration has formed several groups to study the commercialization of Landsat and the weather satellites. The Land Remote Sensing Satellite Advisory Committee, the Business Evaluation Committee, and the Technical Evaluation Committee all evaluated responses to a request for information (RFI). The Commerce

Department issued the RFI in September 1982 for industry comment on the feasibility of Landsat and weather satellite commercialization. The Cabinet Council on Commerce and Trade, chaired by Secretary of Commerce Baldrige, has also studied this question.

The Land Remote Sensing Satellite Advisory Committee, composed of individuals from outside of the Federal Government, reviewed the responses to the RFI. In November 1982, the committee issued a report which emphasized the need for Landsat continuity and recommended that the Government transfer only the space and ground segments of the land and/or weather satellites up to and including the receiving of the raw, unprocessed data. Under this plan, many firms could then enter the data processing, enhancement, and product development end of the Landsat system.

Two Government interagency panels also evaluated the RFI responses. The Business Evaluation Committee concluded that the user market for Landsat is not presently large enough to support a private operation without a Government subsidy. It therefore recommended a gradual commercialization, beginning with the value-added segment. The Technical Evaluation Committee raised several national security concerns and cautioned that a monopoly might harm Government interests.

The Cabinet Council on Commerce and Trade met several times to discuss whether Landsat and/or the weather satellites should be transferred to the private sector. When it met in April 1982, the Council decided that the weather satellites should remain under Government control for national security reasons. The Department of Defense has raised some concerns about the transfer because of the close relationship between the civil and military weather satellites. When the Council met again in December 1982, however, it decided that national security issues could be resolved and recommended that all U.S. civil remote sensing satellites be transferred to the private sector. This recommendation was forwarded to, and later approved by the President.

Following President Reagan's announcement, a Source Evaluation Board was formed to develop and issue an RFP. There are three committees under the Board which will provide: a business evaluation, a technical evaluation, and legislation to pass through the Congress once a final decision is made. According to the current schedule, the Source Evaluation Board will release a draft of the RFP in late-September and invite industry and Congress to comment on the draft through October.

A final RFP will then be released in November or December 1983 and industry will have three months to respond. Following a three month review of the proposals, the Board will send its recommendation, with the best offer or offers from industry, to the Secretary of Commerce. If the Board does not believe that any of the proposals from industry are acceptable, it can also recommend that no transfer be made. The Secretary will then make his final decision, probably in May or June 1984. Based on the final proposal, the Source Evaluation Board will draft legislation to pass through the White House and then to Congress. With congressional approval, the satellite systems could then be transferred to the private sector.

Congress will continue to be involved in resolving some of the issues surrounding the proposed transfer of remote sensing satellite including: system continuity, Government and user costs, the possible creation of a monopoly, Federal subsidization of Landsat, allegations of a Government "give away" of valuable systems, national security, foreign competition, and international cooperation. Current plans to launch only one more Landsat and the long lead time required to procure another Landsat will make it difficult to ensure Landsat continuity. Whether the program is taken over by the private sector or continued by the Government, there will probably be a one year data gap. If the private sector does not take over, the program could end in 1987.

There is also some concern that a private land and weather satellite operator will increase Government and data user costs, especially in the short-term, and the Congress and the Administration will have to decide what costs are acceptable. Critics have warned that a private operator with a guaranteed Government contract could become a monopoly and restrict, rather than encourage, competition in these fields. Objections have been raised that the Government is selling the weather satellites only to convince the private sector to take over Landsat, so that the weather satellites would essentially subsidize Landsat. Should the users of weather satellite data subsidize the development of a commercial land remote sensing system?

Furthermore, because the Government has invested $1.6 billion in the systems, and will receive far less from the private sector, some have called the proposed sale a Government "give away." Should the Government expect to recoup its R&D investment in remote sensing? How should the value of the systems be assessed?

The Defense Department has raised some concerns about national security (primarily because of its use of civil weather satellite data) and will place

some restriction on a private weather satellite operator. The Defense Department may also restrict future land remote sensing operations to ensure national security.

Landsat will face some foreign competition after the French launch their land remote sensing satellite, SPOT, in 1985. Without a firm commitment to a future land remote sensing program, the United States could lose some of its foreign and domestic Landsat data market to the French. If Landsat is not transferred, will the Government commit enough funds to keep Landsat competitive in the international marketplace?

Finally, the United States has encouraged foreign countries to use Landsat data and has freely exchanged weather data with the international community. The United States will have to decide if it wants to continue this international cooperation and what effect commercialization will have on these policies.

Should We Make Products on the Moon?

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By W.F. CARROLL, W.H. STEUREN, R.H. FRISBEE, and R.M. JONES
Jet Propulsion Laboratory, CalTech

By the turn of the century, just a good development cycle away, commercial needs for large amounts of certain materials in Earth orbit may justify producing them on the Moon

THE AUTHORS

WILLIAM F. CARROLL, left, member of the Technical Staff in JPL's Applied Mechanics Div., has been involved in materials R&D and applications for JPL lunar and planetary spacecraft, advanced space mission concepts, and biomedical and solar-energy projects many years. He joined JPL in 1961 after working eight years in the ceramics industry and two years at North American Aviation. **WOLFGANG H. STEURER (M)**, a member of JPL's research team on the utilization of space resources, received a Ph.D. in 1940 at the Univ. of Stuttgart, Germany. During WW II he was in charge of the Materials Laboratory at the German rocket center Peenemunde. Upon coming to this country with the Von Braun team in 1945, he served on various space programs of the Army Missile Command at Fort Bliss, Tex., and Huntsville, Ala. He joined the Convair Div. of General Dynamics in 1958 and JPL in 1977. **ROBERT H. FRISBEE**, a senior engineer in JPL's Propulsion Systems Section, is the task manager of the Advanced Propulsion Concepts Study and a member of the JPL Space Station Trade Study Team. He received a Ph.D. in physical chemistry at the Univ. of California-Santa Barbara in 1978, and taught chemistry at California Polytechnic State Univ. before joining JPL in 1979. **ROSS JONES (M)**, a senior engineer in JPL's Power Systems Section, joined the laboratory in 1976 after receiving a M.S. in aeronautical and astronautical engineering from MIT. Previously he worked two years at Aerodyne Research, Inc., where he modeled infrared signatures of aircraft and rockets. At JPL, he has led a program to identify innovative concepts for future space power systems, and has worked on design studies of electric propulsion systems. He is a member of AIAA Electric Propulsion TC.

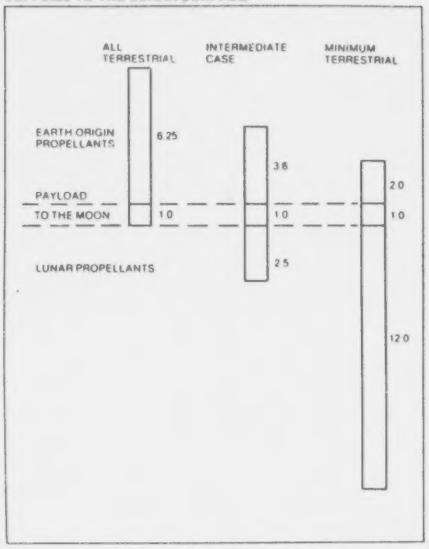
Products from extraterrestrial materials can play a major role in future space operations within the useful lifetime of our first major space station, now in the planning stage. This will not require the dramatic new space undertakings assumed in some studies,[1-3] but rather a moderate program of government and commercial use of space.

Extraterrestrial products such as oxygen can reduce the need for costly, energy-intensive launches from Earth. *It takes seven times more energy to get one kilogram from the Earth's surface to low Earth orbit (LEO) than it does to move one kilogram from the Moon's surface to LEO* (with aerobraking for LEO entry). These facts have led many investigators to study and propose lunar, asteroidal, and Martian materials for space operations.[4,5]

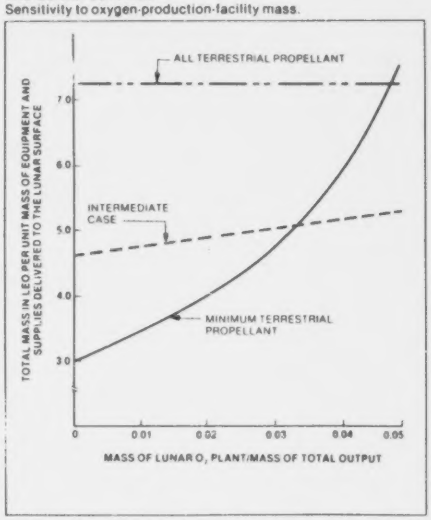
Production, transportation, and use of extraterrestrial materials of course will require equipment and supplies that must be launched from Earth. In fact, the mass of such equipment and supplies represents one of the major constraints on the use of extraterrestrial materials. Analysis has shown what the margin of advantage of extraterrestrial materials might be; has defined the limits on manufacturing and power facilities and on expendables; has set constraints on manned and unmanned operations for maintenance and repair; and has established a basis to evaluate the needs for, and possible impact of, new or improved technology. Rigorous mathematical treatment of this picture is beyond the article's scope but will be reported elsewhere. Here we examine engineering practicality. In what follows we normalize all masses to LEO for comparison to launch systems and space operations.

We look first at the transport of processing equipment from LEO to the lunar surface and of lunar products to LEO and GEO (geosynchronous orbit). We will emphasize conventional chemical propulsion using technology and hardware that can be expected to be in place for LEO to GEO orbit transfer in *less than two decades*. Aerobraking, used here for all cases of chemical propulsion for return to

F-1 SCENARIOS FOR TRANSPORTING EQUIPMENT AND SUPPLIES TO THE LUNAR SURFACE



F-2 TRANSPORTATION OF EQUIPMENT AND SUPPLIES TO THE LUNAR SURFACE
Sensitivity to oxygen-production-facility mass.



LEO, proves necessary for positive payoffs. This technique is already moving toward development for reusable orbit-transfer vehicles (OTVs) for LEO-to-GEO traffic.

Scenarios (F-1) describe transporting equipment or supplies from LEO to the lunar surface to establish, expand, or operate a production facility for three different cases: (1) all O_2 and H_2 propellants are brought from Earth. (2) All hydrogen and some oxygen is brought from Earth; some oxygen is produced on the Moon. (3) Hydrogen is brought from Earth; all oxygen is produced on the Moon.

As expected, the relative advantage of each depends on the "difficulty" of obtaining the lunar oxygen. For the three scenarios, F-2 shows the relation of the O_2 factory to transportation (mass) demands. The "minimum terrestrial" case, using large quantities of lunar-produced O_2, clearly looks best if the oxygen-production facility's mass per unit product can be small. It becomes less attractive rapidly as the facility mass increases. Using some terrestrial oxygen, as in F-2's intermediate case, lowers the sensitivity to the mass of the lunar factory.

T-1 describes several scenarios for transporting lunar products to LEO using conventional LO_2/LH_2 propulsion and aerobraking at LEO. Cases 1, 2, 3, and 5 use the baseline OTV and LTV systems. Case 4 is intended to illustrate limits that might be approached with major improvements in chemical propulsion.

Supplying all of the propellant from Earth (Case 1), keeps deliverable lunar payload less than the mass of the terrestrial propellant required to make the delivery (i.e., payload ratio less than 1.0). Unless future work identifies a lunar product which is somehow superior to its terrestrial competition, there will be no advantage from lunar products under these conditions.

Case 2, using all terrestrial H_2, terrestrial O_2 for return of the OTV to LLO, and lunar O_2 for the rest, shows some potential benefit for lunar products.

The baseline case (Case 3) assumes all terrestrial H_2 and all lunar O_2. It uses the least terrestrial propellant and produces the maximum payload ratio using the baseline transfer vehicles.

Improvement in performance (I_{sp}) and tare weight of the systems (both possible) would improve the margin of benefit from the use of extraterrestrial materials. Case 4 asssumes a zero dry mass of the OTV and LTV and thus represents a limit case for major chemical propulsion improvements. The difference is important but not revolutionary in terms of extraterrestrial materials and their utility.

Finally, Case 5 shows the effect of finding quantities of extractable H_2 or other fuel on the

T-1 LUNAR-TO-LEO TRANSPORTATION EXAMPLES

Case	Conditions	Propellants: Terrestrial O_2	Propellants: Terrestrial H_2	Propellants: Lunar O_2	Propellants: Lunar H_2[a]	Lunar payload to LEO	Payload ratio[b]
1	Baseline OTV—all terrestrial propellant[c]	321[c]	53.1	0	0	66.9	0.18
2	Baseline OTV and LTV; combined terrestrial and lunar O_2.	26.7	17.9	80.5	0	66.9	1.50
3	Baseline OTV and LTV; minimum terrestrial propellant.	0	17.9	107.2	0	40.2	2.25
4	Limit case; zero-dry-mass OTV and LTV	0	13.8	82.7	0	62.7	4.54
5	Assume lunar H_2 available[a]	0	0	89.8	14.9	54.1	∞

[a] Lunar H_2 has been postulated,[7] but not confirmed; results shown for illustration only.
[b] Payload ratio is defined as tons of payload delivered (from the lunar surface to LEO) per ton of terrestrial-origin propellant required in LEO to make the delivery.
[c] Requires multiple OTV trips and staging in LLO.

T-2 MASS OF FACILITIES ESTIMATED FOR PRODUCING O_2 ON THE MOON

In tons.

Process efficiency (product mass/input mass)	0.1		0.2		0.4	
Capacity, tons of product/yr	100	500	100	500	100	500
Processing plant and support						
Processing plant	6.0	20.0	4.8	16.0	3.6	12.0
Teleoperation/communication	1.2	1.5	1.2	1.5	1.2	1.5
Port/storage	2.0	4.0	2.0	4.0	2.0	4.0
Surveyor	0.2	0.2	0.2	0.2	0.2	0.2
Rover	0.2	0.4	0.2	0.4	0.2	0.4
Product transport vehicle	0.3	0.3	0.3	0.3	0.3	0.3
Repair robot	0.5	0.5	0.5	0.5	0.5	0.5
Product containers	1.0	5.0	1.0	5.0	1.0	5.0
Subtotal	11.4	31.9	10.2	27.9	9.0	23.9
Power-generation facility[a]						
All-electric	50	250	25	125	12.5	62.5
50/50 electric/thermal	30	150	15	75	7.5	37.5
Total facility mass						
All electric power	61.4	282	35.2	153	21.5	86
50/50 electric/thermal	41.4	182	25.2	103	16.5	61

[a] Solar to electric at 5 kg/kW$_e$. Solar to thermal at 1 kg/kWh.

Moon. Watson et al have described a model for water-ice in permanently shadowed craters at the lunar poles,[7] but there is no concrete evidence for or against this model. The presence of a usable fuel would profoundly affect the entire program for exploring and utilizing space. The importance of volatiles has been discussed in detail.[8] A future *A/A* article will describe missions to seek usable fuel.

Several other options have been examined at varying levels of detail for transporting lunar products to LEO and GEO including electromagnetic launchers (e.g., rail gun and mass driver), electric propulsion, solar sails, and nuclear propulsion. An electric-propulsion OTV using lunar O_2 as propellant and combined with baseline chemical LTV can yield a payload ratio of ~8, but since the round trip time is ~200 days and the OTV power-supply mass is significant, the real advantage is less than 8. The same electric OTV combined with an electromagnetic launcher for the lunar surface to LLO produces an infinite payload ratio. However, the electromagnetic launcher and nuclear-propulsion technologies are not expected to be well enough established for application in the near future.

Products made using necessarily simple and automated space-production facilities will probably differ from what we make using complex industrial machinery on Earth. Relative function or performance thus need attention. In fact, it is useful to define breakeven performance for potential products.

We can define performance ratio as "how good" the extraterrestrial product is relative to its terrestrial competition for a particular job or function. Using just the quantities of terrestrial propellant for transport of products from the Moon to LEO from T-1, and assuming other factors related to extraterrestrial production to be minor, we can determine minimum breakeven performance ratios. For the baseline chemical-propulsion case (Case 3 in T-1) slightly more than 2 tons of lunar product can be returned to LEO for every ton of terrestrial-origin propellant. To just break even, the ~2 tons of extraterrestrial product must be equal in performance to Earth-origin competition with a mass of 1 ton that could be launched in lieu of the propellant. With conventional propulsion, therefore, the minimum performance ratio just to break even, for lunar products for LEO, will be ~0.5. Even with the limit case of zero dry mass transport vehicles, the break-even ratio is ~0.25. When the effects of other factors related to the production and transport of extraterrestrial products are considered, the break-even performance ratio increases.

In considering metallic components, we note a typical factor of 2× or greater difference between the tensile strength of unalloyed metals and their structural alloy counterparts and another factor of 2× to 6× between the non-heat-treated and heat-treated condition. Obviously, alloying, heat treating, and final machining are possible on the Moon, but each operation adds to the mass of the production and power-generation facilities. Given these mass-adding factors and the minimum breakeven performance ratio of 1/4 to 1/2 (even considering other factors insignificant), parts made from lunar-derived metals should not prove attractive for use in LEO, at least as an early product.

Similarly, it is unlikely that parts made from lunar-surface materials—"lunar bricks"—can meet the minimum performance ratio for structural use.

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They might meet the requirements of radiation shielding or some thermal or electrical insulation.

Delivering lunar products to GEO brings in different specifics than for delivery to LEO, but the net effects on candidate products are similar. To deliver 1 ton of lunar product to GEO takes 1 ton of terrestrial propellant in LEO. However, delivery of terrestrial products to GEO requires the mass of the terrestrial competition plus 3 to 4 tons of terrestrial propellant in LEO. Therefore, the effective payload ratio is 4 or 5 and the minimum break-even performance ratio for lunar products for GEO is 1/4 to 1/5. Although this improves the margin for extraterrestrial materials, it does not make enough difference to significantly modify the general constraints for LEO.

Consider next some limits on the mass of production and power-generation facilities and on expendables. For simplicity, assume that lunar oxygen will be the product delivered as well as a propellant for the transfer vehicles.

F-3 shows "return on investment" for two of the T-2 cases. The curves show tons of extraterrestrial product (O_2) delivered to LEO per ton of total Earth-origin equipment, supplies, and propellants required to produce and deliver the product, as a function of the mass of production facilities and supplies to the Moon. The two cases assume all terrestrial propellant for the transportation of processing equipment from LEO to the lunar surface (see F-2). The other processing-equipment transportation scenarios (not plotted) extend the breakeven points, but only by ~0.01.

For the baseline transport case, all the potential advantage of lunar oxygen disappears if production and power facility, supplies, and expendables exceed ~2% of the total (life-cycle) product mass. Even with the limit case, benefit disappears at ~5%.

Mass of production and power-generation facilities has been estimated for making O_2 on the Moon for a range of process efficiencies, plant capacities, facility lifetimes, and power-supply assumptions. T-2 and F-4 summarize results. Note that the more optimistic cases (high-capacity, high-efficiency, etc.) fall in a range of potential benefit (see lower curve of F-3) and that all high-efficiency cases fall within the range of potential advantage as defined by the upper curve in F-3.

Process efficiency obviously affects energy consumption and the resulting mass of the generating facility. *Thus a high priority for current research should be given to gathering experimental and analytical information that will allow reliable estimates of energy efficiency.*

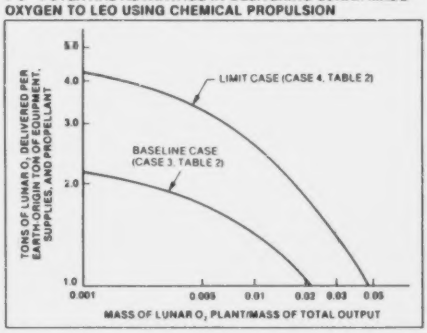
The mass associated with production and power generation will be "amortized" over the total O_2 produced during the facilities' operational lives.

When we compare estimates of facility mass (F-4) with the limits of the facilities plus supplies (F-3) we see that the expendable or consumable supplies must be held to a very small fraction of the product mass—about 1% or less. In molten-silicate electrolysis experiments, Kesterke used 2/3 to 3/4 by weight flux and was unable to recover or recycle any of it.[9] At the lower level, the mixture contained ~4 kg flux per kg of oxygen. A recycling recovery of ~99.75% would be necessary to keep consumption down to 1% of product mass. Such a level would be difficult with multistage terrestrial facilities, and unlikely with the simple facilities that will be practical on the Moon.[10] Thus, the use of expendable items such as fluxes, process aids, and sacrificial electrodes—even in small quantities—appears to be impractical. Recognition of this limitation led to our recent demonstration at JPL of the production of metals and oxygen by the electrolysis of molten (simulated lunar) magma without the use of flux or sacrificial electrodes.[11]

Similarly, lunar products that require wet chemical processes seem impractical for use in LEO, since a large mass of reagents and equipment would have to be imported from Earth. Also, they would probably require too much recycling of reagents.

The above discussion concerns oxygen for both transport propellant and product. Some more general conclusions are possible. Typically, "high technology" products that involve many separate process steps—electronic devices and conventional silicon photovoltaics—require elaborate processing facilities with a mass much greater than 1-2% of the mass of product made over the plant's lifetime. Such "high-technology" products made from lunar

F-3 POTENTIAL ADVANTAGE IN DELIVERING LUNAR-MADE OXYGEN TO LEO USING CHEMICAL PROPULSION



materials do not appear to be viable for use in LEO. However, their potential for lunar use, and possibly even for GEO, cannot be ruled out with the current state of knowledge.

Crew operations will probably be needed only for site surveys, installation and startup of facilities, and infrequent visits for nonroutine maintenance. Routine operation and maintenance will be handled by combined automation and remote control.

The mass in LEO required for crew operations in relation to the mass of a potential extraterrestrial product will be an important consideration.

The Apollo system provides a useful reference. It was capable of delivering two people, with equipment and supplies, to the Moon and returning them to Earth. It started with a mass of more than 100 tons in LEO.[12]

To illustrate the relationships, assume deliveries of lunar O_2 to LEO for satellite orbit raising at the rate of 100 tons per year with a 2:1 advantage, that is, 100 tons of lunar O_2 delivered for every 50 tons of terrestrial-origin equipment and supplies put into LEO for lunar-product production and transport. Under these circumstances, a single Apollo-type manned mission every two years for operation or maintenance would more than eliminate the entire advantage of the use of extraterrestrial O_2. For a "market" of 500 tons per year and the margin of 2:1, occasional Apollo-scale maintenance missions might be acceptable.

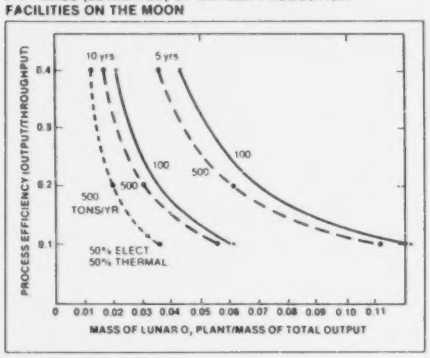
At the level of 100 tons of lunar O_2 assumed above, one or two manned missions for site surveys and installation and startup would be acceptable if the operation lasted about 10 years or more.

As an example of the other extreme, consider lunar O_2 delivered to LEO for life support on a manned space station. At 0.84 kg (1.84 lb) per person-day (~300 kg per person-year) a station with a crew of 20 would require only 6 tons per year.[13] Even if lunar O_2 could be produced and delivered at 2:1 advantage, more than 30 years would be needed to recover the investment of a single Apollo-type mission for exploration and startup. Obviously, using the lunar source for such a small supply will be practical only in combination with larger quantities of O_2 expected to be required for orbit raising.

In conclusion, we might summarize results in terms of the two key factors: origin of the material and point of use.

The principal effort has been on lunar materials for use in LEO, using chemical propulsion with aerobraking for transport. Other propulsion options have been examined with less rigor, but in sufficient depth to reach the following conclusions concerning lunar products for use in LEO.

F-4 MASS (ESTIMATED) OF OXYGEN-PRODUCTION FACILITIES ON THE MOON



- To make the use of any lunar produced material practical, lunar oxygen or some unconventional form of propulsion, such as an electromagnetic launcher, will be needed for its transport.
- Products with performance directly or nearly proportional to mass—O_2 propellant and lunar products for radiation shielding—can have an advantage over terrestrial competition.
- Structural metal-alloy parts will probably not be practical, and can be so only if their performance closely approaches terrestrial competition.
- Components made from unrefined or partially refined lunar-surface material such as "lunar bricks," primarily for structural purposes, are *very unlikely* to be competitive.
- Products which require production facilities and processing aids or reagents on the Moon of more than 1-3% of the life-cycle product mass are *very unlikely* to be competitive. This would appear to preclude consideration of conventional electronics or silicon photovoltaics, which require extensive facilities, and wet chemical processes, unless they entail little facility mass and their reagent recovery and recycling approaches 100%.

As to lunar products for use in GEO, they have somewhat greater advantage over terrestrial competition than lunar products delivered to LEO, but not enough to change the conclusions regarding lunar products for LEO.

Analyses similar to these have been completed for other origins and points of use of extraterrestrial materials, with the following tentative conclusions.

Asteroidal products for LEO:

- Transport of products from some asteroids requires less energy than from the Moon, but the differences using conventional chemical propulsion are not sufficient to reach conclusions different

from those regarding lunar products for LEO.

- Because asteroids have very low escape velocity, near-term electromagnetic launcher technology may be practical for bringing asteroid material to LEO. But its applicability, use, and constraints are too uncertain for definitive assessment at this time.

Lunar materials for lunar-surface use:

- Lunar materials can have an advantage over terrestrial competition for lunar use, even with a performance disadvantage of the order of 100. Even such as structural "crude" metal-alloy parts and "lunar bricks" may be advantageous.

The analyses described here indicate that high-performance lunar products—O_2 and radiation shielding—probably can be produced by relatively simple equipment and should be commercially attractive for use in LEO or GEO as soon as these sites show a market for quantities in the range of 10^2-10^3 metric tons per year. Experts see this as possible by the turn of the century—not much more than a well-conceived development cycle away.

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MATERIALS ENGINEERING IN THE SKY

By John C. Bittence, Senior Editor

Processing in space could create a whole new world of materials

By John C. Bittence, Senior Editor

Some time, probably before 1982, the Space Shuttle will deliver the first scientific payload into orbit. Once in place, the Skylab will begin humming as dozens of experiments, scientific and military, public and private, are activated. Somewhere deep within the Shuttle, in a five-cubic-foot container, a movie camera will whir while a small cloud of moisture begins to crystallize into a snowflake. The first of hundreds of materials-science experiments destined for Space Shuttle delivery and pickup is taking place. It's a study to observe the growth of a snowflake under gravity-free conditions.

In latet flights, scientists hope to produce superpure glass, inexpensive solar cells, and a host of metallic alloys that don't even exist on earth. By 1984, between 100 and 120 materials experiments per year will be conducted in space. Eventually, these experiments may turn into full-fledged manufacturing operations to produce earth-bound products. Ultimately -- though certainly not in the near future -- raw materials for these operations may be mined and imported from the moon.

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The attraction of 0g

Why will we go thousands of miles above the earth to process materials and make parts? Primarily, because the space environment offers a combination of conditions that are difficult, if not impossible, to duplicate on earth. First of all, space offers a cheap solar-energy supply. In addition, near-perfect vacuum (down to 10^{-14} torr) is right at hand, temperature extremes between −200 and +200°F (−130 and +93°C) are readily available, and the environment is always free from atmospheric-related corrosives and impurities.

The most valuable condition in space, however, is the almost total absence of gravitational force. Although a trace, or microgravity (up to $10g^{-6}$), is always present, this value is practically zero for most materials applications.

Near-zero gravity does not result from the satellite being beyond the earth's pull, because it is not. Although gravitational forces in orbit are much less, the earth's pull on a satellite is still significant. Rather, low gravity, or weightlessness, results from the balance of forces that keep the satellite and its contents in orbit. Microgravitational forces arise when this delicate balance is upset by simple movements of the craft caused by orbit corrections, equipment operations, or even motion of the occupants. "We are always dealing with microgravity, never zero gravity," points out Frank J. Jelinek, associate section manager, Battelle-Columbus Laboratories. "But for most purposes, we regard it as 'zero.' "

Weightless conditions in orbit may be a bonanza to metals researchers. At "zero g," everything floats, so molten materials can be solidified in vacuum without ever contacting a container wall. In addition, at zero g, mixtures of light and heavy substances stay mixed. Materials solidified at zero g are homogeneous; there's no settling out of more dense constituents, and no turbulence during freezing.

One of the first phenomena researchers want to study in space is the solidification of immiscible metals — metals that normally don't form alloys on earth because one is pulled out of solution by gravity before the molten material solidifies. Over 500 such binary metallic systems with miscibility gaps on earth have been identified. Scientists are eager to determine whether any of these materials are superconductors, superplastic, or possess any unusual magnetic or electrical properties when solidified in zero gravity. "The potential here is tremendous," observes Battelle's Alan J. Markworth, a physicist anxious to get the Space Shuttle under way. "Although we've primarily been studying the aluminum-indium system (because it's easy to work with), there are hundreds of alloys that could develop into something useful," Markworth adds.

Miracles from immiscibles

Battelle has been studying miscibility-gap metals since 1973, but only recently have they been able to test out their theories under low-gravity conditions. Alloys of Al-40In and Al-70In, cast during a few precious seconds of near-zero gravity during the free-fall trajectory portion of SPAR II rocket flights from Marshall Space Flight Center, yielded some suprising results.

First, in the absence of gravity, lesser known physical phenomena become extremely important. Surface tension, for example, plays only a minor role in metal casting and solidification on earth, where gravity is the dominant force. In space, however, in the absence of gravity, surface tension plays an active part.

In addition, thermal viscosity and thermal conductivity in the cooling

metal can become bothersome. In one Battelle rocket experiment reported by Markworth, thermal gradients, rather than gravity, induced segregation — and immiscibility — in an Al-In casting. One theory suggests that thermocapillary flow (the Marangoni Effect) is the culprit leading to segregation in the absence of gravity.

Gravity-driven convection currents also are absent from the molten metal in space. The result is a finer microstructure than is possible on earth. In some cases, unexpected and unidentified phases have turned up in low-gravity castings. Paradoxically, and totally opposite from earth-bound metal behavior, slowly cooled metal in space has a finer microstructure than rapidly cooled samples.

Scientists admit that they are just beginning to understand the behavior of immiscible metals. In fact, most of the experiments to date have raised more questions than answers. Ultimately, scientists agree that space experimentation will contribute substantially to our technical understanding of materials behavior, including solidification dynamics, vaporization and condensation, and diffusion.

Specific metallurgical achievements that scientists hope will result from zero-gravity experimentation include manufacture of superhigh-strength magnets in space for use on earth, production of extremely strong, fine-grained welds between metals not weldable on earth, continuous casting of dispersion-strengthened metals, melt-

A pinch of basalt

Although it's still a generation away, researchers are already predicting the day when we will be mining the moon for raw materials. Most likely, these materials will be delivered to orbiting factories that manufacture huge structures in space. A 13-mi^3 satellite to collect solar power for the earth, for instance, could be made of 90% lunar materials.

Lunar mining is attractive because it takes 22 times more energy to send material into orbit from the earth than from the moon. In addition, a wealth of metals and minerals are available right on the surface of the moon, as the table shows.

Notably absent from the lunar crust is hydrogen, thus making the production of water impossible. Moon mining and beneficiation will have to rely on anhydrous techniques. Also, because of low gravity and lack of an earth-like atmosphere, mining will probably be unmanned.

Materials the moon holds in store for us

Element	Earth rank	Earth composition, ppm by weight	Moon composition, ppm by weight	
			Highlands	Mare
Oxygen	1	466,000	417,000	446,000
Silicon	2	277,000	212,000	210,000
Aluminum	3	81,300	69,700	133,000
Iron	4	50,000	132,000	48,700
Calcium	5	36,300	78,800	106,800
Sodium	6	28,300	2900	3100
Potassium	7	25,900	1100	800
Magnesium	8	20,900	57,600	45,500
Titanium	9	4400	31,000	3100
Hydrogen	10	1400	54	36
Phosphorous	11	1050	660	500
Manganese	12	950	1700	675
Carbon	17	200	100	100

Data courtesy Convair Div. General Dynamics.

ing and casting of highly reactive metals without the need for crucibles or molds, production of ultrapure metals, and the development of new families of intermetallics and immiscible alloys.

Superfibers, superglass

Engineering fibers on earth made from glass, carbon, or ceramics have only a fraction of their theoretical strength. Surface irregularities, grain boundaries, and crystalline defects, all introduced during manufacture, reduce fiber strength and ductility. Space-produced fibers, on the other hand, probably will more closely approach theoretical properties.

Techniques have been proposed for growing high-strength, monocrystalline fibers, or whiskers, of materials such as silicon carbide to be used as reinforcement for metals and composites. In an early, rocket-borne experiment with silver, whisker-strengthened with 5% SiC, bending strength was improved by 20% and deflection under load improved by a factor of seven.

Even more impressive, however, are predictions for improvements in optical glass and solar silicon made in space. Some of the first materials that will be studied in the Space Shuttle are ultrapure laser glass and fibers for optical wave guides.

Battelle has developed a new technique for producing glass and glass-ceramics that is especially adaptable to the special conditions of space. Called the Sol-Gel process, the scheme requires both the zero g and high vacuum of outer space (ME 7/80).

In the realm of glass and ceramics, researchers expect another materials bonanza. "Magnetic" glass ($FeBO_3$, containing 70% ferromagnetic iron) has great potential for magneto-optical devices. Unfortunately, this unusual material cannot be made on earth in a form suitable for these devices. It can, however, be produced by containerless melting in space.

Glass products with dispersion, refractive, and other properties unavailable in earth-made materials possibly can be created in space. For instance, lasers can be made more efficient by increasing the calcium content of the Nd-Ca-Li-Al silicate glass optics. Unfortunately, this can't be done on earth, since contact by calcium with the container walls during melting causes devitrification. In space, however, high-efficiency laser optics can be made by containerless melting. According to an Owens-Illinois study, improvement in laser efficiency should be well worth the cost of processing in space.

Similar predictions are made for space-processed solar silicon and various semiconductor materials such as Ga-As. According to some estimates, high yield from space-processed semiconductor materials will easily offset the high costs of space processing. The added benefits of space processing will stem from improved reliability of space-made semiconductors.

Typical glass and ceramic products

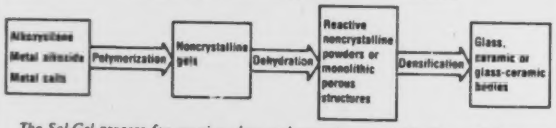
The economics of space processing

NASA calls it their "getaway special." For $10,000, anyone can tuck a 200-lb payload into the bowls of the Space Shuttle for delivery — along with the rest of the cargo — into orbit around the earth. An additional $10,000 of the cost is government subsidized, so the total cost for a trip into space is about $100/lb, or 100 times less than the cost in 1960. By 1990, a trip into orbit should cost $25/lb — still an expensive ride.

On the other hand, efficiency of solar-energy generators can be at least doubled if critical silicon cells were made in microgravity space. The rejection rate for certain earth-grown, high-purity semiconductor wafers can be reduced from present-day high rates to practically "zero" when they are grown in orbit. And an ultrapure version of a biological material called collagen produced in space would be almost priceless for medical treatment of burns, replacing blood vessels, and producing artificial corneas.

The cost benefits of producing certain materials in space, especially in minifactories that can be refurbished and returned to orbit, are indeed worth the steep transportation costs.

Sol-gel process for glass and ceramics



The Sol-Gel process for growing glass and ceramic parts is ideally suited for space production of optical waveguides. According to Battelle, noncrystalline gels can be produced on earth and sent into orbit for melting. An accoustical positioning device would suspend the material during dehydration and densification to prevent contamination. Glass bodies would then be returned to earth to be drawn into low-loss waveguide fibers.

that scientists hope to develop from space experimentation include "selective-wavelength" optics, holographic storage devices, better integrated circuits, ferroelectrics, and high-performance lenses and mirrors.

MPS ready to fly

In 1978, NASA recognized the potential benefits from materials experimentation in space by awarding the Materials Processing in Space program (MPS) to TRW Defense and Space Systems Group. The assignment was to develop a new facility for materials R&D in space with the ultimate possibility of performing commercial work in orbit. According to NASA, the MPS facility will be used to "conduct applied research in fluids technology and materials solidification relating to electronic materials, metals, ceramics, glass and chemicals." Manufacturing processes outlined as being particularly adaptable to the space environment include melting and casting, vapor deposition and powder metallurgy.

Two MPS payloads emerged. The first, the manned facility for fluids experiments and vapor crystal growth, will be installed in one of the Spacelabs. The second unit, a pallet-mounted experimentation system, will ride in the Shuttle's cargo bay. This unit is designed to perform more than two dozen solidification experiments in a high-temperature furnace by preprogrammed control.

By about 1984, the NASA power module for free-flying orbital missions should be ready, and TRW's MPS program will be ready for its next step — launching of the Materials Experimentation Carrier (MEC) which will link up with the power module for missions of up to 120 days. By 1987, MEC will become a manned, fully serviceable, continuously orbiting facility, called the Materials Experimental Module, MEM-1. It will be used for advanced R&D materials and pilot-plant production. By 1990, MEM-1 will be replaced by MEM-2, whose specific design and mission are yet to be established.

The mine in the moon

Some researchers envision the day when a facility similar to the MEMs would be supplied with raw material from the moon, or perhaps from nearby mineral-rich asteroids, although beneficiation of these elements will require novel technology. Unlike earth-bound beneficiation, which relies on water, acids, bases and an atmosphere, moon processing of raw materials probably would be based on electrostatic beneficiation powered by solar energy. Because of low gravity and lack of an earth-like atmosphere, mining on the moon would probably be totally automated.

The rationale for moon mining stems from the lower escape velocity — approximately one-fifth that of the earth — required to remove a mass of material from the surface. A NASA-funded study by General Dynamics, Convair Div., proposes that materials be catapulted from the moon's surface and captured by space "garbage trucks" for batch delivery to the production facility for processing. Ultimately, NASA would consider building entire space stations in space, deriving 90% of the raw material for construction from the

moon. Lunar material would cut costs of in-orbit construction by about one-third.

When will all this take place? "These things are *all* conceivable," points out Battelle's Jelinek. "Probably by the time your children and my children are senior citizens, they will be a reality." General Dynamics researchers agree, observing that current and projected capabilities to produce solar energy sufficient to carry out lunar mining will not even exist by 1990.

A National Research Council committee, studying NASA's original MPS proposal in 1978, was even more cautious. "The committee has not discovered any examples of economically justifiable processes for producing materials in space," they reported. "When gravity has an adverse effect on a process, stratagems for dealing with it can usually be found on earth that are much easier and less expensive than recourse to space flight."

On the other hand, Europe, Japan, and the USSR have given top priority to materials science experimentation in space. In a General Accounting Office review last winter of space-processing programs proposed or carried out by NASA so far, the U.S. Congress was taken to task for its low funding and support of materials experimentation in space. In fact, according to GAO, foreigners could easily assume the lead in materials science in space, since materials experiments in early Shuttle/Spacelab missions will be predominantly performed by other nations.

The European Space Agency, ESA, currently developing the first Spacelabs in cooperation with a consortium of European businesses, has selected materials processing as one of the two disciplines to be included in the first flight. ESA has a list of about 120 materials science experiments they would like to propose for the first and subsequent Spacelabs.

Begins with a snowflake

From manned factories in orbit to unmanned strip mining of the moon . . . it will all start by growing a tiny snowflake aboard the Space Shuttle. The snowflake will be grown because two Japanese 16-year-olds suggested the experiment, and Battelle was commissioned to include it in one of the first of two Space-Shuttle payloads for it which it purchased flight options. The teenagers won a contest sponsored by a Tokyo newspaper, *Asahi Shimbun*, out of more than 16,000 entries proposing ideas for research experiments that could be conducted aboard the NASA shuttle.

Toshio Ogawa and Yasuhiko Oda wanted to see whether snowflakes grown in the weightlessness of space differed from those grown under gravitational influence of the earth. Battelle's Alan Markworth liked the idea; he's anxious to determine whether the basic platelet flake will grow in three dimensions. Differences in morphology between earth and space-grown flakes will be evaluated for scientific significance. "Although," concedes Markworth, "a lead-off experiment such as this will have a lot of public appeal, too. Especially in Japan." Cost of the snowflake project: $100,000, which includes a $10,000 ticket for the ride in the Shuttle. The sole product of the experiment will be a length of four-color film. ■

REPORT BY THE

Comptroller General

OF THE UNITED STATES

Effects On Users Of Commercializing Landsat And The Weather Satellites

In March 1983, the administration proposed to transfer the National Oceanic and Atmospheric Administration's satellites--a land-observing satellite, called Landsat, and the weather satellites--to the private sector. This report discusses how these satellites are used worldwide and how their commercial operation might affect users.

In November 1983, the Congress enacted legislation to prevent the sale of the weather satellites; the administration is proceeding with its efforts to commercialize Landsat. In considering legislation to authorize a sale, the Congress should consider whether the sales terms proposed by the administration adequately protect the interests of Landsat users in the United States and abroad.

GAO/RCED-84-93
FEBRUARY 24, 1984

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON D.C. 20548

B-214057

The Honorable Jack Brooks
Chairman, Subcommittee on Legislation
and National Security
Committee on Government Operations
House of Representatives

The Honorable Charles McC. Mathias
United States Senate

The Honorable John C. Stennis
United States Senate

The Honorable Edward Zorinsky
United States Senate

This report discusses how the National Oceanic and Atmospheric Administration's remote sensing satellites--Landsat and the weather satellites--are used by federal agencies, other U.S. organizations, and foreign governments and how users might be affected by the commercialization of these satellites. It also outlines issues regarding the commercialization of Landsat for consideration by the Congress as it takes up legislation to authorize its sale. As requested by your offices, the report presents the information we developed on the weather satellites, even though their sale has been prevented by recent congressional action. Our classified report to you entitled National Security Implications of Commercializing Landsat and Weather Satellites (GAO/C-RCED-84-1, Feb. 1, 1984) discusses commercialization in relation to national security issues.

As arranged with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time we will send copies to the appropriate House and Senate committees, the heads of departments and agencies whose programs we discuss, Members of Congress, and other interested parties.

Milton J. Socolar

Acting Comptroller General
of the United States

COMPTROLLER GENERAL'S REPORT

EFFECTS ON USERS OF COMMERCIALIZING LANDSAT AND THE WEATHER SATELLITES

D I G E S T

The Department of Commerce's National Oceanic and Atmospheric Administration operates two remote sensing satellite systems--the weather satellites and Landsat--which produce data with worldwide uses. In March 1983, the administration announced its decision to transfer these satellites to private enterprise and rely on the private sector in the future for the data these systems supply. The administration wants to commercialize Landsat because it believes that the private sector can develop a market for Landsat data better than the federal government and can help the United States retain its international lead in this technology. Inasmuch as the Landsat activities are not presently economically self-sustaining, commercialization of the weather satellites was proposed so the private satellite owner would be assured of a source of revenue while the Landsat market was being developed.

The Chairman, Subcommittee on Legislation and National Security, House Committee on Government Operations, and Senators Mathias, Stennis, and Zorinsky, asked GAO to examine several aspects of the proposed sale, including

--its effect on the national security of the United States,

--the uses which federal agencies have or expect to have for satellite data,

--the effect of the sale on nonfederal United States and foreign government users, and

--conditions which could be included in the contract transferring the satellites to the private sector.

The national security aspects of the proposed sale are discussed in GAO's classified report entitled National Security Implications of Commercializing Landsat and Weather Satellites (GAO/C-RCED-84-1, Feb. 1, 1984). Recent congressional action has prevented the sale of the weather satellites, but the information GAO developed on these satellites is included in

this report at the request of the Members of Congress who asked for the GAO review. (See pp. 3 to 5, and 27 to 42.)

LANDSAT USES

Since 1972, the United States has maintained in orbit a series of land sensing satellites called Landsats. The current Landsat is the fourth in the series. Landsat "senses" the earth's surface and sends the data back to earth in a form which can be processed into photographic images or computer-compatible tapes. Landsat data are used around the world to estimate and manage crop production; explore for minerals, including petroleum; make and revise maps; and accomplish other purposes. Landsat data are used in the United States by federal and state agencies, industrial and service businesses, and universities. Landsat is also used extensively by foreign governments which operate 10 ground stations to pick up Landsat signals. The federal government had spent, through March 1983, about $477 million to build, launch; and operate Landsat 4; to build a satellite to succeed Landsat 4; and for the Landsat ground system. The U.S. government charges Landsat users a fee designed to recover operating costs, but not building or launching costs. (See pp. 2 and 3.)

USER CONCERNS RAISED BY THE PROPOSAL TO COMMERCIALIZE LANDSAT

A change from government to commercial operation of Landsat could mean major changes for Landsat users. GAO discussed these possibilities with a sample of users, including representatives of 18 federal agencies, 16 other U.S. users, and 10 foreign countries. The views GAO obtained on commercialization were those of organization officials and may not represent the formal position of the organizations themselves. (See pp. 7 and 8.)

Federal and nonfederal domestic users of Landsat believed the present limited market for Landsat would not allow a private operator to make a profit at current prices. They were concerned that with monopolistic control over the supply of data, a private operator could increase prices and also reduce data quality. Both federal and nonfederal users believed that

a commercial operator would not perform sufficient research and development. (See pp. 11 and 12, and 23 to 25.)

Representatives of several nonfederal users recommended that commercialization of Landsat proceed in stages beginning with data distribution. These users said that a gradual turnover of the system to the private sector would improve the chance for successful commercial operation by allowing time for development of a profitable market. (See p. 25.)

Private companies which buy Landsat data from the government for analysis and resale--termed "value-added" companies--were concerned that a private operator would use its control over the source of data to drive them out of business. (See p. 23.)

Under federal operation, Landsat data have been broadcast directly from satellites to receiving stations operated by foreign governments. The United States has followed an equal access data distribution policy, making Landsat data available to all interested parties, including the country from which the data were sensed, at the same time and on the same terms.

Foreign governments were concerned that commercial operation of Landsat might change these data distribution arrangements. They were concerned that a private operator might, for commercial reasons, stop transmitting data to their ground stations--very often facilities in which they had invested considerable resources--or that the operator would increase prices to the point that they could no longer afford the data. Also, the foreign governments said that a private company might find it profitable to sell, for the exclusive use of outsiders, information on their countries' resources or activities, which would be harmful to their economic or national security interests. (See pp. 17 to 19.)

Although most federal and other U.S. Landsat users believed that commercialization could affect them adversely, some believed that private control of the satellites would help improve service and increase marketing of data. (See pp. 9 and 23.)

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HOW THE REQUEST FOR PROPOSALS ADDRESSES USER CONCERNS

Following the March 1983 announcement of the administration's decision to commercialize the satellites, the Department of Commerce set up a Source Evaluation Board to prepare requests for proposals. Requests for proposals were drafted for both Landsat and the weather satellites, but because the Congress enacted legislation in November 1983 to prohibit the sale of the weather satellites, only the Landsat request was issued. Responses to this request for proposals are due at the end of February 1984.

The Landsat request for proposals requires offerors to describe the type of land remote sensing system they would build to replace the current system and the operating and pricing policies they would follow. It also indicates that the government is willing to provide financial assistance to a private operator and invites offerors to state what form of financial assistance they would prefer. According to Source Evaluation Board officials, financial assistance is being considered because the current market for Landsat data is not strong enough to support a profitable operation. (See pp. 5 to 7.)

Complete information on the operating characteristics of a commercial land sensing system and the associated costs will not be known until a contract is agreed upon by the government and a private operator. However, the request for proposals does address many of the concerns raised by federal Landsat users. For example, the request for proposals requires a private operator to orbit a sensor which provides data at least equal to the current Landsat operational sensor. In addition, a prospective operator must describe methods for improving data coverage and timeliness and for ensuring that data quality is maintained. The request for proposals also states that the government plans to continue land remote sensing research and development.

However, the request for proposals satisfies fewer of the concerns raised by international and nonfederal Landsat users. For example, subject to U.S. government approval, the private operator could terminate broadcasts to foreign ground stations and change the

present federal data distribution policy by refusing to sell data to a country from which the data were sensed. A private operator might find these changes commercially advantageous. The request for proposals does not describe the criteria that the federal government would apply to requests by a private operator for these changes. But because Landsat will be a commercial venture, economic considerations may influence government policymaking to a greater extent than in the past. The private operator would also be permitted to enter the value-added industry. According to Source Evaluation Board officials, the request for proposals does not impose all the restrictions on a commercial operator that international and nonfederal U.S. users want, because the request is designed to encourage full commercial development of a land remote sensing system with a minimum of federal regulation. (See pp. 12, 13, 19, 20, and 25.)

MATTERS FOR CONSIDERATION BY THE CONGRESS

The administration plans to propose legislation to the Congress to authorize commercialization. The Congress may set out in this legislation requirements for commercial operation in addition to or different from those contained in the request for proposals.

In deliberating on this legislation, the Congress may wish to consider the following:

--Should a private Landsat operator be required, under terms and time frames specified by the Congress, to continue present arrangements for broadcasting data to foreign ground stations?

--Should a private operator be required to continue the traditional U.S. government policy of providing a sensed country with equal access to data obtained on its territories and activities?

--Should protection be provided to firms in the value-added business so that they can compete with the private Landsat operator? For example, the Landsat operator could be required to make data available to all value-added firms on the same terms and as soon as the data are ready for analysis by the operator itself.

--Should a step-by-step approach to commercialization, beginning with data distribution, be an alternative to control of the whole system. (See pp. 20, 25, and 26.)

Any legislation authorizing the commercialization of Landsat must balance the financial interests of the private operator against the concerns of Landsat users that unregulated commercial operations will adversely affect their interests. Potential private operators will in turn consider whether legislatively or administratively established terms and conditions make private Landsat operation economically attractive.

HOW THE CANCELLED PLAN TO COMMERCIALIZE THE WEATHER SATELLITES WOULD HAVE AFFECTED USERS

GAO discussed the proposed plan to commercialize the weather satellites, now cancelled because of congressional action, with officials of 7 federal agencies, 14 other U.S. users, and 11 foreign countries which use U.S. weather satellite data. Federal and domestic nonfederal weather satellite users wanted to avoid higher charges for weather data they now receive free or at low cost. They also wanted the current level of data and services to be maintained. Private companies that did value-added work on weather satellite data believed that entry of a private operator into their business would jeopardize their existence. Foreign users of weather satellites were concerned about charges for satellite data previously provided at no cost through programs such as the United Nations' weather information exchange system.

Although most federal and other U.S. satellite users said that commercialization could affect them adversely, some believed that private control of the satellites could help improve service and data marketing.

The unissued weather satellites request for proposals sought to ensure that, for the most part, commercial operation of weather satellites would not affect current users. The private operator would have been required to continue present services and supply the U.S. government with data and services to continue present international meteorological

cooperation. Users of the weather satellite communications services, however, might have faced price increases and the private operator would have been allowed to enter the value-added business. (See pp. 27 to 42.)

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ABBREVIATIONS

GAO	General Accounting Office
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
RFP	request for proposals

CHAPTER 1

INTRODUCTION

On March 8, 1983, the administration announced its decision to transfer the federal government's operational civil remote sensing satellites to the private sector. The satellite systems to be included in this transfer were Landsat (the land remote sensing satellite) and the weather satellites. Since the data produced by these satellites are used by numerous federal, international, and private organizations, the effect of any changes in the operation of Landsat and the weather satellites would be widespread. Questions were raised among all of these groups concerning the advisability of the transfer, the terms and conditions which should be included in the transfer, and the effect the transfer would have on users.

The Chairman, Subcommittee on Legislation and National Security, House Committee on Government Operations, and Senators Mathias, Stennis, and Zorinsky asked us to examine several aspects of the proposed transfer, including

--its effect on the national security of the United States,

--the uses which federal agencies have or expect to have for satellite data,

--the effect of the sale on nonfederal U.S. users and foreign government users, and

--possible conditions which could be included in the contract transferring the satellites to the private sector.

In November 1983, after the completion of our review, the Congress enacted Public Law 98-166 prohibiting the transfer of the weather satellites to the private sector. The requestors nevertheless asked us to report the information we had developed on the weather satellites as well as Landsat.

The national security aspects of the proposed sale are discussed in our classified report entitled National Security Implications of Commercializing Landsat and Weather Satellites (GAO/C-RCED-84-1, Feb. 1, 1984).[1] The remaining aspects of the proposed sale, including the reaction of federal, international, and private users of satellite data, are discussed in the following chapters.

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[1]See also our earlier report entitled Costs and Uses of Remote Sensing Satellites (GAO/RCED-83-111, Mar. 4, 1983).

CHARACTERISTICS AND USES OF THE SATELLITE SYSTEMS

The United States currently has five civil operational remote sensing satellites in orbit--one land remote sensing satellite (Landsat) and four weather satellites. All of these satellites were developed by the National Aeronautics and Space Administration (NASA) and are operated by the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA).

Landsat

The first Landsat was launched in 1972; three replacements have been placed in orbit since then. The present Landsat, Landsat 4, was launched in July 1982 but is malfunctioning. A replacement for Landsat 4 is scheduled to be launched in March 1984.

Landsat "senses" the earth's surface and sends the data back to earth in a form which can be processed into photographic images or computer-compatible tapes. Landsat 4 carries two instruments: the multispectral scanner and the thematic mapper.[2] The multispectral scanner, which was one of the instruments carried on the previous Landsats, is considered the operational sensor. The thematic mapper is a more advanced sensor but is considered experimental.

Data transmitted from Landsat are received by the Goddard Space Flight Center in Maryland and by 10 foreign ground stations which are operated under cooperative agreements with the U.S. government.[3] The data received at the Goddard Space Flight Center are transferred to the Department of the Interior's Earth Resources Observation Systems Data Center in South Dakota where they are processed, stored, and sold as photographic images or computer-compatible tapes.

Landsat data are used by numerous federal and state agencies, foreign countries, university researchers, private businesses, and individuals. The following table shows the percent of Landsat

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[2]The multispectral scanner monitors materials on the earth's surface--water, crops, and forests for example--by measuring the light waves which they reflect. The thematic mapper is a more sophisticated sensor which monitors the earth's surface in greater detail than the multispectral scanner.

[3]In calendar year 1983, each of the following countries operated one ground station: Argentina, Australia, Brazil, Canada, India, Japan, South Africa, and Thailand. In addition, the European Space Agency operated two ground stations.

products sold at the Earth Resources Observation Systems Data Center to each of the user groups for fiscal year 1983.

FY 1983 Landsat Purchases From the Earth Resources Observation Systems Data Center

Customer	Products	Dollar
	----------Percent----------	
Federal government[a]	47	75
State/local government		
Academic	4	3
Industrial	10	9
Individual	3	1
Non-U.S.	34	11
Total[b]	100	100

[a]Federal government purchases may be higher than shown since some of the other categories of customers may include contractors for federal agencies.

[b]Figures do not add due to rounding.

Purchases at the Data Center amounted to about $7 million in fiscal year 1983. The prices of Landsat products are designed to recover operating but not building or launching costs. As of August 1983, the prices for photographic images ranged from $26 to $235; the prices for computer-compatible tapes ranged from $650 to $2,800. For the first 9 months of fiscal year 1983, the latest period for which information was available, Landsat operating costs amounted to about $22 million.

Landsat data have a variety of uses, including mapmaking, mineral exploration, crop estimation, and wildlife habitat assessment. More detailed information on the ways federal, private, and foreign entities use Landsat data is provided in the following chapters.

The weather satellites

The U.S. weather satellite systems were first authorized in 1961 when the Congress directed the Department of Commerce to establish a satellite system that would continuously observe and report on worldwide environmental conditions. The government has launched and operated numerous weather satellites in the years since then. At present, the government has four civilian operational weather satellites in orbit--two polar orbiters and two geostationary satellites.

The two polar orbiting satellites circle the earth a total of four times daily to provide global coverage of cloud patterns, surface temperatures, atmospheric humidity, and other environmental data. The two geostationary satellites continually view North and South America and the Atlantic and Pacific Oceans as they orbit the earth above the equator at the same rate the earth turns. The information provided by the geostationary satellites includes cloud motion and wind data, precipitation estimates, and frost data. The satellites are valuable in making daily weather forecasts, in researching the environment, and in detecting and tracking severe storms.

Both groups of satellites use a variety of weather and environmental sensors to obtain the required data. These data are transmitted to two command and data acquisition stations in Wallops Island, Virginia, and Gilmore Creek, Alaska. Because the polar orbiting satellites regularly move beyond transmitting range from these stations, arrangements have been made with the French Government to receive some data at their command and data acquisition station at Lannion, France. These data are then relayed to the United States. In addition to the command and data acquisition stations, there are more than 800 direct readout stations around the world, owned mostly by foreign governments, which receive data at no cost from the polar orbiting or geostationary satellite sensors.

Geostationary satellite images can also be obtained by telephone link. To receive satellite data by this method, a user must acquire appropriate telephone communications and terminal display equipment and pay both an initial connection fee and an annual service fee. The images themselves are provided at no cost.

Historical and analyzed data from both polar orbiting and geostationary satellites are obtained by purchasing the data from NOAA's Satellite Data Services Division or by subscription to NOAA's Weather Facsimile System. This system transmits National Weather Service forecasts and other data via the geostationary satellites.

The capabilities of the polar orbiting and geostationary satellites go beyond sensing weather information from the earth's surface. For example, geostationary satellites carry a data collection system to collect and relay environmental data observed by a variety of remotely located platforms, such as river and tide gauges, buoys, ships, airplanes, and automatic weather stations. The polar orbiting satellites have a similar capability through a French-produced system which not only collects data from moving platforms but also provides information on where the platform was located at the time the data were received by the spacecraft. The newer of the two polar orbiting satellites also has the capability to monitor emergency radio broadcasts from ships or planes through a receiver called Search and Rescue Satellite Aided Tracking.

The federal government is the largest user of weather satellite data. NOAA's National Weather Service, the primary

recipient, uses satellite data to issue warnings about hurricanes, tornadoes, and severe storms; to gather environmental data for daily weather forecasts; and for research. The second largest federal user is the Department of Defense, which uses data from the civil polar orbiters to supplement its own Defense Meteorological Satellite Program. Weather satellite data are also disseminated abroad through a United Nations-sponsored system for the free, international exchange of weather data.

Other users of weather satellite data include state and local governments; university researchers; and private companies and individuals, such as the news media, airlines, and farmers. Chapter 5 of this report provides more detailed information on the users of weather satellite data.

STATUS OF THE ADMINISTRATION'S PROPOSED SALE OF THE SATELLITES

The proposal that Landsat be transferred to the private sector first received presidential endorsement in 1979 during the Carter administration. Following a lengthy review of the nation's space policy, President Carter decided to give NOAA responsibility for operating Landsat and announced the goal of eventually transferring it to the private sector. However, the administration also affirmed its intention to ensure continuity of Landsat data through the 1980's by launching three additional satellites in the Landsat series.

The Reagan administration terminated the government's commitment to ensuring Landsat data continuity through the 1980's because it believed that commercialization can occur more quickly. Instead of launching three more Landsats, the current administration intends to launch only one more. In addition, on July 13, 1981, President Reagan requested the Cabinet Council on Commerce and Trade, chaired by the Secretary of Commerce, to determine the best method of transferring Landsat to the private sector and to assess the advisability of transferring the weather satellites to private ownership. In December 1982 the Council recommended the transfer of Landsat and the weather satellites. President Reagan announced his endorsement of this recommendation on March 8, 1983. In congressional testimony, the Secretary of Commerce said that the administration wants to commercialize Landsat because it believes that the private sector can develop a market for Landsat data better than the government and help the United States retain its international lead in this technology. Commercialization of the weather satellites was proposed to allow a private satellite owner an assured source of revenue while the Landsat market was being developed.

In June 1983, the Secretary of Commerce chartered the Source Evaluation Board on Civil and Remote Sensing to draft a request for proposals (RFP). The Board issued a draft RFP in October 1983 to obtain industry input. The draft RFP would have allowed private firms to bid for one or more of the three systems:

Landsat, the polar orbiting weather satellites, and the geostationary weather satellites. In November 1983, however, the Congress enacted Public Law 98-166, which prohibited the use of funds by the Source Evaluation Board to develop or issue an RFP for the sale or lease of the weather satellites. In response, the Board cancelled plans to issue an RFP for the weather satellites. The final RFP for Landsat was issued on January 3, 1984. Responses to the RFP are due by February 29, 1984.

The objective of the RFP is to establish as quickly as possible a commercial land-observing satellite program which is subject to the least possible government regulation. Offerors are required to submit proposals to build and operate a satellite system to begin operating in 1987, after the last government-built Landsat stops operating. Offerors are also encouraged to buy or lease the government's system for its lifetime. This system includes (1) Landsat 4 and its successor satellite scheduled for launch in March 1984, (2) satellite command, control, and other functions at the Goddard Space Flight Center, (3) ground or other systems for satellite tracking and communications, and (4) data processing and distribution at the Earth Resources Observation Systems Data Center.

According to officials of the Source Evaluation Board, the market for Landsat data is not strong enough to make operation of Landsat profitable at this time. The RFP states that the government is willing to provide financial support, such as loans or loan guarantees, during the early years of private operation and invites offerors to indicate what form of assistance they would prefer, but the government's ultimate objective is to purchase data, over the counter, from a self-sustaining commercial operation. The RFP also indicates that the government is willing to negotiate with a private operator for launch services.

The RFP requires an offeror to specify the type and cost of data and services which it will provide after the transfer. The RFP does not set a limit on the prices that a private operator could charge but does indicate that volume of federal data purchases will depend on data cost. After responses to the RFP have been received and evaluated, the Department of Commerce will select the preferred offeror and propose legislation to the Congress to authorize the commercialization of Landsat. If the legislation is passed, Commerce will contract with the successful offeror for a commercial Landsat system. The Congress can refuse to authorize the commercialization or may pass legislation which requires commercial operations different from those proposed by the selected offeror. Any operating requirement imposed in legislation would control the terms of a contract between Commerce and the commercial operator.

Any legislation authorizing the commercialization of Landsat must balance the financial interests of the private operator against the concerns of Landsat users that unregulated commercial operations will adversely affect their interests. Potential

private operators will in turn consider whether legislatively or administratively established terms and conditions make private Landsat operation economically attractive.

OBJECTIVES, SCOPE, AND METHODOLOGY

As requested by Chairman Brooks and Senators Mathias, Stennis, and Zorinsky, we identified the principal federal, international, and private users of satellite data and their uses of the data and discussed with them which conditions the users believed should be included in the contract transferring the satellites to the private sector. In our discussions with users we used a structured interview approach. Different sets of questions were developed for each of the user groups. Each user within each group was asked the same questions. Their responses have been tabulated in the report. In accordance with the requestors' instructions, we did not obtain agency comments on the report. The audit work on this assignment was done between May and September 1983 and, with the exception of not obtaining agency comments, was performed in accordance with generally accepted government auditing standards.

To obtain information on the federal uses of Landsat and weather satellite data we spoke with officials from 23 agencies. These agencies were in the Departments of Agriculture, the Interior, Commerce, Energy, Labor, Transportation; or were independent agencies like the Environmental Protection Agency, NASA, and the Smithsonian Institution. These users represent most of the federal civilian agencies which made significant use of Landsat and weather satellite data in 1982. See appendix I for a description of how these federal agencies use the satellites.

Information on the international implications of the sale was gathered by interviewing officials from 3 federal agencies, 5 international assistance organizations, and 11 foreign countries. The federal agencies contacted were the Department of State and the major suppliers of satellite data to other countries: the Agency for International Development and the Department of Commerce. Representatives from the World Meteorological Organization and other United Nations' agencies, World Bank, Inter-American Development Bank, and Asian Institute of Technology were interviewed because their organizations have funded projects involving the use of Landsat or weather satellite data. Finally, we visited foreign ministry, space agency, or meteorological officials in Argentina, Barbados, Brazil, France, Germany, India, Italy, Japan, Peru, Thailand, and the United Kingdom. Selection of these countries was made following discussions with officials from the Agency for International Development, NOAA's National Environmental Satellite Data and Information Service, and the National Weather Service. Countries were selected to include representative industrialized and developing countries in various geographical locations that use Landsat and weather satellite data.

We spoke with officials of 28 private and state government organizations selected after discussions with NOAA officials to achieve a representative cross section of nonfederal users.[4] The organizations we contacted are in industries or consumer groups which are among the largest users of satellite data. The users included large and small private weather services, large and small oil exploration service companies, television weather services, data processing companies, a state government, a university, a public utility, and an airline. These groups were selected to include a diversity of satellite data users in a variety of geographical locations. The views on commercialization we obtained were those of organization officials and may not represent formal positions of the organizations themselves. A total of 2,980 nonfederal organizations bought Landsat data from the Earth Resources Observation Systems Data Center in fiscal year 1982. (See ch. 5 for the number of nonfederal users of the various weather satellite data and services.) We also reviewed the Department of Commerce's RFP to determine the extent to which it addressed concerns raised by users about commercialization.

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[4]Fourteen of the organizations used only Landsat data, 12 used only weather satellite data, and 2 used both.

CHAPTER 2

COMMENTS FROM FEDERAL AGENCY OFFICIALS ON THE COMMERCIALIZATION OF LANDSAT

Most of the federal Landsat users believed that the cost of Landsat data would probably increase under private operation, and almost all believed that increases would cause them to curtail or even stop using Landsat data. Federal users were also concerned that a private operator's efforts to cut costs might result in a reduction in the type and quality of data and services and in remote sensing research and development. The only potential benefit which was mentioned by more than two users was that a private owner would probably improve the marketing of Landsat data. Virtually all of the federal users believed that the sales contract should include terms and conditions that would protect their interests.[1]

The commercialization process has not proceeded far enough to determine how federal costs will be affected or how the character of land remote sensing data may change. However, the RFP for Landsat does address many of the concerns raised by federal users.

BACKGROUND ON FEDERAL USERS OF LANDSAT DATA

Twelve federal civilian departments or independent agencies[2] purchased Landsat data from the Earth Resources Observation Systems Data Center in calendar year 1983:

Department of Agriculture
Department of the Army, Corps of Engineers (Civil Works)
Department of Commerce
Department of Energy
Department of the Interior
Department of Justice
Department of Labor
Department of Transportation
Environmental Protection Agency
National Aeronautics and Space Administration
National Science Foundation
Smithsonian Institution

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[1]This chapter discusses all federal uses of Landsat except for national security and international assistance. International uses of Landsat are discussed in chapter 3 of this report. National security uses are discussed in our classified report entitled National Security Implications of Commercializing Landsat and Weather Satellites (GAO/C-RCED-84-1, Feb. 1, 1984).

[2]Excluding national security and international assistance agencies.

According to Data Center records these agencies spent about $2.7 million on Landsat products in calendar year 1983 through August 17.[3]

We spoke with program managers from 18 units[4] in seven departments and agencies. These departments and agencies included the largest, regular federal Landsat users. The managers we contacted use Landsat data to support projects which range from estimating worldwide crop production to predicting the course of forest fires. Examples of a few of the uses of Landsat data follow. (See app. I for individual descriptions of the ways federal agencies use Landsat data.)

--The Geological Survey uses Landsat data to assist in activities such as monitoring coastal shoreline changes, assessing the effects of floods and other natural disasters, and producing a national land use/land cover map series.

--The Fish and Wildlife Service uses Landsat data for planning National Wildlife Refuge activities.

--The Foreign Agricultural Service uses Landsat data to help estimate foreign crop production.

--The Bureau of Land Management uses Landsat data to map vast tracts of public lands and for resource inventories.

--The Corps of Engineers uses Landsat data for purposes such as studying the impact different flood levels could have on cities and communities.

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[3]Data Center records understate federal agency purchases by not including purchases made on the agencies' behalf by contractors.

[4]The Department of Agriculture's Foreign Agricultural Service, Statistical Research Service, Soil Conservation Service, Agricultural Research Service, and Forest Service; the Department of the Army's Corps of Engineers; the Department of the Interior's Geological Survey, Bureau of Land Management, Bureau of Reclamation, Fish and Wildlife Service, National Park Service, Bureau of Indian Affairs, Bureau of Mines, and Office of Surface Mining Reclamation and Enforcement; the Department of Labor's Mine Safety and Health Administration; the Department of Energy; the Environmental Protection Agency; and the National Aeronautics and Space Administration.

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FEDERAL USERS' CONCERNS ABOUT POTENTIAL INCREASES IN THE COST OF LANDSAT DATA

The possibility of increases in the cost of satellite data was the principal concern of most federal users of Landsat data we contacted. Landsat users in 14 of the 18 agencies said that cost increases were likely if the satellite was sold to the private sector. Users believed that a private owner would charge more for Landsat data because the current prices are too low to fully recover costs. NOAA has priced Landsat data to recover operating costs; a commercial operator would charge prices designed to recover the costs of building and launching Landsat as well as operating it. Under federal operation Landsat costs have been high. As of March 31, 1983, the federal government had spent about $477 million to build, launch, and operate Landsat 4; to build a replacement for Landsat 4; and for ground systems.

Users in 16 agencies we contacted believed that an increase in the cost of Landsat data would either prevent them from continuing to buy the data or reduce the amount they could buy. Users in seven agencies said that no satisfactory alternative to Landsat data exists. For example, a Bureau of Land Management official said that Landsat plays a key role in helping the Bureau manage federal lands. According to the official, satellite data is irreplaceable for vast, relatively inaccessible areas such as parts of Alaska.

FEDERAL USERS' CONCERNS ABOUT DATA, SERVICES, AND RESEARCH

Landsat users in 14 of the 18 agencies expressed concern about the type or quality of data and services they would receive from a private owner. These users believed that selling Landsat would result in poorer service, including interruptions or delays in data delivery. Another major concern was that certain types of data used by the agencies might no longer be available. Limited data availability was seen as resulting from the private owner's desire to discontinue unprofitable data types. Seven of the users believed that the products they now buy would be discontinued since they are likely to be low-selling items. In a related issue, users were concerned that a private owner might not continue archiving data for future use since this would probably not be profitable. Some of the users said that archived data was very useful in supporting their agencies' programs.

Officials of seven of the agencies were concerned that the quality of data they received might deteriorate. Users cited inexperience and increased emphasis on operational economies as reasons for possible reductions in data quality.

Seven users believed that research and development would be slowed under private ownership. These users believed that the federal government should continue to perform research and development for Landsat. For example, a Forest Service official said that a private firm might perform some research, but the government would have to do research in areas where commercial profits are unavailable.

TERMS AND CONDITIONS SUGGESTED BY FEDERAL USERS

Officials from 17 of the 18 Landsat-using federal agencies we contacted believed that if Landsat is sold, the federal government should include specific terms and conditions in the sales contract to protect the government's interests. Users from 16 of the 18 agencies supported a provision that would state the type of data that must be collected by the private owner of Landsat. Users from 15 of the agencies believed that standards for data quality should be required in the sales contract. Users in 13 agencies advocated provisions to ensure the timeliness of data delivery, the frequency of data collection, the continuation of research and development, and the establishment of a federal board to oversee the private owner's management of Landsat. All of these provisions were viewed as protecting the agencies' continued access to the type and quality of data needed to support their programs.

RFP TREATMENT OF FEDERAL USER CONCERNS

Full performance characteristics for the commercial Landsat system will not be established until a contract is reached between the government and a private operator. In addition, the costs of Landsat products and the amount of the federal subsidy to the commercial operator will not be known until a contract is signed. However, the RFP does require an offeror to orbit a sensor which provides data equal to or better than the current Landsat operational sensor. In addition, an offeror must describe methods for improving data coverage and timeliness and for ensuring that data quality is not reduced.

The RFP indicates that it is the administration's policy to continue federal research and development. It states that:

> "It is the U.S. Government's strong belief that an aggressive, continuing Federal R & D effort in advanced remote sensing technology is critical to maintaining a U.S. leadership position in civil space technology, as well as to advancing the understanding of changes to global earth processes and their long-term impacts."

In addition, the RFP indicates that the government will continue to archive Landsat data which a commercial operator does not want to inventory.

The RFP also states that the government will have authority to oversee the operations of the commercial land sensing system, including authority to correct deficiencies that might affect operations. According to Source Evaluation Board officials, a federal interagency board will be established to advise the Department of Commerce, which will administer the contract with the commercial operator, on the operator's performance.

CHAPTER 3

INTERNATIONAL IMPLICATIONS OF COMMERCIALIZING LANDSAT

Landsat is used extensively by other countries. These countries are concerned about how commercialization would affect the cost and accessibility of Landsat data. The RFP would permit major changes in the international distribution of Landsat information.

HOW OTHER COUNTRIES OBTAIN LANDSAT DATA

Countries obtain Landsat data in several ways. First, countries purchase data directly from the Department of the Interior's Earth Resources Observation Systems Data Center. According to the Data Center's records, foreign users bought 34 percent of the Landsat tapes and photographic images sold at the center in fiscal year 1983. Receipts from foreign users represented 11 percent of the Center's $7 million sales during the same period.

Second, countries can receive direct Landsat broadcasts. In 1983, foreign countries and the European Space Agency received the data directly from Landsat at 10 ground stations. Ground stations are operated under agreements with the United States, requiring them to pay a $600,000 annual fee and a fee for each Landsat product distributed. These countries also sell the data received by their ground stations to customers in other countries. In 1982, the latest year for which data were available, foreign ground stations received revenues of $2.5 million from distributing about 59,000 Landsat tapes and images.

In addition, foreign countries obtain Landsat data and technical assistance through cooperative activities with federal government agencies. The largest federal user of Landsat data for international projects--the Agency for International Development--budgeted about $500,000 for Landsat data in fiscal year 1983. Other federal agencies that use Landsat to aid in various international efforts include the U.S. Geological Survey, which has sponsored Landsat training courses for the international user community; and the Bureau of Land Management, which has cooperated with other nations on projects involving Landsat data. In addition, the Bureau of Reclamation helped Mexico use Landsat to measure salinity in the Colorado River.

Finally, foreign countries obtain Landsat data through projects funded by international organizations such as the World Bank, the United Nations, and the Inter-American Development Bank.

HOW OTHER COUNTRIES USE LANDSAT

We spoke with government officials responsible for space and remote sensing programs in 10 countries about how Landsat data is used.[1] Nine of these countries operate their own Landsat receiving stations or are members of the European Space Agency, which operates two receiving stations.[2] In addition, we spoke with officials of several international organizations that use Landsat data: the World Bank, the Inter-American Development Bank, the Asian Institute of Technology, and some United Nations' agencies. Generally, these officials told us that:

--Landsat has demonstrated value in a number of areas but is used mostly on a research and development or demonstration basis rather than an operational basis since program managers are still learning how to use it.

--The uses of Landsat data are expected to increase in number and variety as users gain experience and satellite technology advances.

--A commercial market for Landsat data is years away.

--Investments made by developing countries in acquiring the capability to receive and use Landsat data represent significant commitments of their governments' resources.

--Landsat has unique advantages over nonsatellite survey techniques for obtaining broad-scale geographic information.

In the countries we visited, Landsat has been used for a variety of purposes, including mapmaking and inventorying and monitoring natural resources. These Landsat uses are particularly important for the developing countries where less is known about the land and its resources than in the more technically advanced nations. Some examples of Landsat's uses follow:

--Brazilian officials said that Landsat had proven especially valuable for monitoring sugar cane--an important crop used both as food and in manufacturing synthetic fuels. Brazilian space agency officials said that the satellite data were needed because Brazil's large land area made the use of aerial photography for surveying the crop impractical.

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[1]Argentina, Brazil, the Federal Republic of Germany, France, India, Italy, Japan, Peru, Thailand, and the United Kingdom.

[2]Of the countries we visited, only Peru does not operate a Landsat ground station or is not a member of the European Space Agency.

--Peru has acquired Landsat data from Brazil and the United States to produce its first nationwide topographic map. Peruvian officials said that the nature and location of the nation's natural resources are not fully known because about two-thirds of the nation has never been accurately mapped. The officials said that mapmaking through aerial photography is too expensive and that flying in remote regions of Peru is too dangerous. The officials added that the speed at which Landsat provides information is especially important in a country like Peru, where natural disasters such as earthquakes, landslides, droughts, and floods can rapidly change roads, rivers, and agricultural conditions.

--Thai officials told us that increasing population has caused more and more land to come under cultivation. The impact of this expanded farming was not clear until Landsat images showed deforestation occurring at an alarming rate. Ground surveys and aerial photography had not disclosed the full dimensions of the problem. After seeing the Landsat pictures, the Thai Government strengthened controls on the clearing of forests.

--In India, Landsat's images of shrinking lakes provided graphic evidence of the effects of recent droughts and contributed to government decisions to provide relief to affected areas.

The more industrialized countries use Landsat data for a variety of purposes, including mapping, urban planning, agriculture, and research. For example, the National Remote Sensing Center in Farnborough, England, provides data to governmental entities, commerical organizations, and academic institutions. Governmental entities have accounted for 53 percent of the data sales from this center in recent years.

The European countries we visited believe that while Landsat data are very useful, a commercial market will develop in the next 5 to 15 years only as users gain experience and technology advances.

Foreign officials also told us of some future uses of Landsat:

--Brazil hopes to use Landsat on an operational basis for agricultural crop surveys and improved identification of deforested areas.

--Peru wants to use Landsat for land-use monitoring, monitoring marijuana and coca leaf production, monitoring the effects of floods and droughts, and identifying landslides.

FOREIGN COUNTRIES' CONCERNS ABOUT THE COMMERCIALIZATION OF LANDSAT

Officials of the countries we visited were not opposed to the commercialization of Landsat per se but were concerned about possible changes that private ownership might bring. Specifically, they expressed concern about the potential for

--data sales policies contrary to their economic or national security interests;

--termination of direct satellite transmission to their ground stations or changes in the satellite signal, requiring expensive ground station alterations; and

--increased prices forcing reductions in data purchases.

Data sales policy

The United States has traditionally followed a policy of making Landsat data available to everyone, including the country over which it was sensed, on equal terms. Foreign countries, in turn, are required by their agreements with the United States to distribute data acquired by their Landsat ground stations in the same manner. This data distribution policy has muted criticism by countries about surveillance within their boundaries. Representatives of the developing countries we visited believed that their governments would object if a commercial satellite operator changed this policy. For example, they said that if Landsat data on natural resources in their own countries were available to others but not to themselves, they would be placed at an unfair economic disadvantage. They believed that this type of sales policy might be adopted to increase profits. In addition, they were concerned that as sensors on board the satellites become more sophisticated, the satellites could be used to acquire and distribute military intelligence harmful to their national interests.

Representatives of the Indian Space Research Organization said that one country's use of remotely sensed data from another country raises issues of national sovereignty. They cited a paper prepared for a 1982 United Nations conference on "The Exploration and Peaceful Uses of Outer Space" in which the Indian government said:

> "India has always maintained that surveillance and remote sensing are but two faces of the same coin. . . . This very contentious issue arises out of conflicting national needs and interests which lead to deep mistrust and mutual suspicion of each other's motives among contending nations.

. . . . .

> "Clearly . . . there is a need for timely and unrestricted supply of data from the sensing state to the sensed state. But dissemination of data to third countries should not take place without following accepted and agreed procedures."

Indian officials said that a policy which did not give India equal access to all data acquired on India might lead to complaints by the Indian Government.

In a message delivered to the same United Nations conference, the President of Brazil expressed concern about the possibility that remote sensing could be used against the interests of a sensed country:

> " . . . [remote sensing from space] affects traditional concepts of security, violating the notion of national privacy and . . . marching towards the violation of individual privacy. Remote sensing impinges on the sovereignty of States over their natural resources and it may prejudice the capacity of countries of negotiating the sale of their agricultural products at fair and equitable prices. This is an instrument both valuable and dangerous."

The developed countries have also endorsed open distribution of satellite data. Leaders of several European nations, Japan, and the United States, meeting at Williamsburg, Virginia, in May 1983, approved the following statement of policy:

> "In view of the inherently global benefits of remote sensing, extensive international participation and the strong interest expressed by numerous countries in the United Nations and other international fora, the Summit members recognize the important broader international context within which Summit member remote sensing activities are conducted. In this regard, throughout the above activities, the members of the Economic Summit . . . support the need to assure timely, public nondiscriminatory data dissemination and to seek continued availability of satellite data."

Transmission to foreign ground stations

Officials from several countries were also concerned that a private sector satellite owner would for commercial reasons stop broadcasting to foreign ground stations. Representatives of the developing countries, in particular, believed that their governments had made major investments in equipment, software, and training to receive and use Landsat data and would react negatively to the loss of direct reception. For example, Thai officials reported that about half of the annual budget of their National

Research Council, the principal government agency for sponsoring scientific research, is used for operating a Landsat ground station and processing Landsat data. The officials said that Thailand had recently spent about $10 million constructing the Landsat receiving station and buying equipment, an amount which they consider a major outlay for scientific purposes. Thai officials also said that developing countries would find it very difficult to understand a shutoff of data to their ground stations in view of their significant investments. Thai officials said that Thailand provides a benefit to the entire Southeast Asian region by making data available to other countries at less than its own costs to receive and process them.

The President of Argentina's space agency reiterated to us a position taken by eight Latin American countries represented on the United Nation's Committee on the Peaceful Uses of Outer Space. These countries took the position that nations operating remote sensing satellites should assure countries operating ground stations of continued access to data and assistance in making ground station modifications required by technical changes in the satellites. Representatives of Brazil, one of the countries adopting this position, told us that Brazil had spent about $40 million over 10 years to receive and use Landsat data.

Another concern frequently expressed by foreign officials was that commercial operation of Landsat might result in sharp price increases which would force them to limit their acquisition of data. Foreign government officials generally said that funds for Landsat data were limited, especially since most Landsat uses were in the research and development area. Representatives of several countries said that recent increases in the price of Landsat products had already reduced sales.

In summary, it was clear from our discussions with foreign officials that they regarded Landsat as an important tool for resource management and other purposes and were concerned about disruptions that commercial ownership might bring. Officials in several countries we visited said that the United States had built considerable goodwill abroad and provided effective foreign economic aid by supplying Landsat data worldwide at relatively low prices.

The RFP for Landsat does not address foreign concerns

The RFP does not fully address the concerns raised by foreign Landsat users. The RFP does not require a private operator to continue present relationships with foreign ground stations. Subject to federal government approval, a private operator could terminate agreements with a foreign Landsat ground station operator. In addition, the RFP does not require the private operator to retain the current U.S. policy of equal data distribution. The private operator could sell data on a country's resources to outsiders for their exclusive use. The RFP does not indicate the

criteria the government would apply to requests by a private operator to terminate transmission of data to foreign ground stations or revise the U.S. government's traditional policy of equal data distribution. The private satellite operator could set prices for foreign customers at its discretion.

MATTERS FOR CONSIDERATION BY THE CONGRESS

International reaction to a commercial Landsat system which quickly stopped broadcasting directly to foreign ground stations and denied a country information developed from remote sensing over its national territory is likely to be negative. In deciding on legislation to authorize the transfer of Landsat to the private sector, the Congress should consider whether a private Landsat operator should be required to

--continue present arrangements for broadcasting data to foreign ground stations under terms and time frames specified by the Congress and

--continue the traditional U.S. government policy of providing a sensed country equal access to data obtained on its own territories and activities.

CHAPTER 4

COMMENTS FROM NONFEDERAL USERS OF LANDSAT

Thirteen of the 16 nonfederal users of Landsat data we contacted were opposed to commercializing the current Landsat system at the present time.[1] Most of these believed that further market and technological developments are necessary to make the system commercially viable. Most users believed that a single company would not have the resources necessary to operate the current Landsat system. The majority of the users were concerned that a private company's inability to meet expenses would negatively affect data prices, continuity and availability of data, and investment in research and development. Six users--including those in the value-added service business[2]--were also concerned about the private owner having a monopoly of satellite-sensed land data.

Four of the 16 Landsat users cited potential benefits from commercialization, such as improvements in quality and marketing of data and services. Users also made suggestions for terms and conditions the government should include if commercialization takes place.

BACKGROUND ON NONFEDERAL USERS OF LANDSAT DATA

Nonfederal users purchase Landsat images and computer-compatible tapes from the Earth Resources Observation Systems Data Center in Sioux Falls, South Dakota. However, some of the users acquire additional data directly from foreign ground stations and through trades with other users. The following table shows the number of nonfederal U.S. customers by group at the Data Center in calendar year 1982 (the latest year for which information was available).

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[1]See chapter 1 for details on the nonfederal users we interviewed. Also, the views we obtained on commercialization were those of organization officials and may not represent formal positions of the organizations themselves.

[2]A value-added service is any service that is added to the raw data after the data are processed and formatted by the government for public dissemination. Such services would include making those products more useful to end users by enhancing, analyzing, and interpreting the standard satellite film or computer tape products.

Nonfederal Users of Data Center FY 1982

Nonfederal users	Number
Colleges/universities[a]	323
State and local governments[b]	73
Industry	1,041
Other or unclassified	1,543
Total	2,980

[a]Since the University of Alaska acts as a distribution center for other academic institutions, the actual number of college or university users may be higher.

[b]Includes an unknown number of foreign embassy purchasers.

The following table shows the number and dollar amounts of image and digital items sold to nonfederal U.S. users by the Data Center in fiscal years 1981 to 1983.

Summary of Landsat
Data Sales to Nonfederal U.S. Users FY 1981-83

	Image items		Digital items		
FY	No.	Dollar amount	No.	Dollar amount	Total dollar amount
1981	51,511	$758,617	2,176	$439,972	$1,198,589
1982	39,109	777,914	2,487	612,580	1,390,494
1983	9,269	471,543	585	329,660	983,685[a]

[a]Includes thematic mapper and other new products, totaling $182,482, which are not included as multispectral scanner image or ditigal items.

Landsat data are used in a variety of ways in the nonfederal sector. For example:

--Energy exploration companies use Landsat data to develop reconnaissance maps which are used in oil, gas, and mineral exploration operations.

--Value-added service companies use the data to provide various products and services, e.g., geological and

engineering studies, resource maps, and complete computer systems for processing and displaying Landsat data.

--State governments use Landsat data for mapping and surveying agricultural lands, marine environments, and other natural resources.

--Universities use satellite data to aid in solving engineering, geological, agricultural, and natural resource problems and as a teaching aid.

NONFEDERAL USERS' CONCERNS ABOUT COMMERCIALIZATION OF LANDSAT

Most users opposed the immediate commercialization of the current Landsat system. Eleven users believed that a private company would not have the resources to make the current system commercially viable and would raise Landsat data prices significantly to defray the system's high operational costs. Thirteen were also concerned that a private company's attempt to cut its operational costs would adversely affect availability or continuity of data and investment in Landsat research and development. Twelve of the 16 users believed that since a private company would not invest in the costly, high-risk research and development necessary to advance the system's technology, commercialization would jeopardize potential future Landsat applications and the U.S. position as world leader in land remote sensing. Half of the users said that the system was not now commercially viable and that attempting to commercialize it would retard its development.

Six users--including value-added service businesses--were concerned that a monopoly would be created if a single company owned and operated the system. These users and six others were concerned that a private operator could exercise its proprietary control of the Landsat system to discriminate in its distribution of the data and charge unreasonable prices. This control could jeopardize the existence of companies in the value-added industry, most of which are small businesses.

The table on page 24 summarizes the nonfederal users' opinions and concerns.

Potential benefits cited by nonfederal Landsat users

The majority of the users could not see any benefit to selling Landsat. However, four users believed that transferring the system to the private sector could result in a savings to the government. Four users also believed that a private company would improve on the quality and timeliness of service of the Earth Resources Observation Systems Data Center.

Summary of Nonfederal Landsat Users' Opinions and Concerns Regarding Commercialization

User's organization[a]	Opinion on immediate commercialization of the entire Landsat system	Would commercializating Landsat create problems in the following areas?			
		Monopoly	Discriminatory/ unreasonable pricing	Continuity and quality of data or service	Decrease in research and development
American Soc. of Photogrammetry	Opposed	No	Yes	Yes	Yes
Arco Oil & Gas Co.	Opposed	Yes	Yes	No	Yes
Amoco Production Co.					
Bechtold Satellite Technology Corp.	Opposed	Yes	Yes	Yes	No
Cartwright Aerial Surveys	Not opposed	No	Yes	Yes	Yes
Earth Resources Data Analysis Systems	Not opposed	Yes	Yes	Yes	No
Earth Satellite Corp.	Opposed[b]	Yes	Yes	No	Yes
An exploration geologist	Opposed	No	No	Yes	Yes
The GEOSAT Comm., Inc.	Opposed	No	No	Yes	Yes
Metrics, Inc.	Not Opposed	No	No	No	No
Mobil Research & Development Corp.	Opposed	No	Yes	Yes	Yes
Pecten International Co.	Opposed	No	Yes	Yes	No
State of Florida Department of Transportation, Topographic Bureau	Opposed	Yes	Yes	Yes	Yes
Sun Exploration & Production Co.	Opposed	No	Yes	Yes	Yes
Terra-Mar	Opposed	No	No	Yes	Yes
University of Florida	Opposed	No	Yes	Yes	Yes

[a]The views expressed were those of organization officials and may not represent formal positions of the organizations themselves.

[b]Opposed if Landsat operator could enter the valued added business, which the RFP permits.

NONFEDERAL USERS' SUGGESTIONS FOR COMMERCIALIZATION TERMS AND CONDITIONS

Ten users recommended that the government ensure the continuity of long-term, high-risk land remote sensing research and development. The users believed that strong government support is necessary to stimulate development of new technology in the field. A few users expressed concern that if the United States did not maintain a viable system, foreign satellite owners might control the land remote sensing market.

Eight users also recommended that controls be established --e.g., price regulations and performance standards for quality of data and service--if a single company owns and operates Landsat.

Seven users recommended that the commercialization of the Landsat system should be a staged process commencing with the ground segment. For example, some suggested that the data distribution functions carried out by the Earth Resources Observation Systems Data Center might be turned over to the private sector first. They believed that if the government continues operating Landsat's space segment and performing high-risk research and development, the private sector could develop (1) a viable market for Landsat products and (2) "next generation" computers to keep in step with sensor technology. The users believed that during the transition period the value-added industry would play an important role in marketing Landsat products. One user also believed that as Landsat technology advances, a range of industries would develop to provide launch, reception, and dissemination services aimed at meeting the needs of the market.

How the RFP addresses nonfederal users' concerns

The RFP addresses some of the concerns raised by nonfederal domestic users of Landsat. As discussed in chapter 2, the RFP indicates that the government will continue to perform research and development on remote sensing from space. In addition, the RFP requires a minimum technical capability for a commercial Landsat operation and requires the private operator to describe the performance features of its system. However, the RFP does not permit a phased approach to the commercialization of Landsat, and it permits the private operator to enter the value-added business.

MATTERS FOR CONSIDERATION BY THE CONGRESS

Fundamental purposes of the RFP are to rapidly divest the government of its land remote sensing operations and to encourage the commercial development of land remote sensing with minimum government supervision. Therefore, the RFP calls for the immediate takeover of the entire Landsat system, satellite and ground operations included, and does not establish special safeguards for the protection of value-added businesses. Therefore, in

considering legislation to commercialize Landsat, the Congress should consider two questions:

--Should a phased approach to the private operation of Landsat, beginning with the data distribution functions currently carried on by NOAA, be an option to controlling the whole system?

--Should protection be provided to firms in the value-added business to enable them to compete with a private Landsat operator? For example, legislation might require the Landsat operator to make data available to all value-added firms on the same terms and as soon as the data are ready for analysis by the operator itself.

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CHAPTER 5

DOMESTIC AND FOREIGN USERS' CONCERNS ABOUT COMMERCIALIZATION OF THE WEATHER SATELLITES

Foreign governments, federal agencies, and other U.S. organizations use weather satellite data chiefly for monitoring and forecasting weather, particularly severe and potentially dangerous weather. The data are also used to route ships and airplanes, make agricultural projections, and for research. Most foreign nations participate in the United Nations' World Meteorological Organization, which arranges for the free international exchange of weather information, including satellite data. The United States, as well as foreign nations, benefits from this exchange.

Although Public Law 98-166 prohibited the commercialization of the weather satellites, we are reporting the information we collected on these satellites at the request of Members of Congress who asked for this review.

FEDERAL USERS OF WEATHER SATELLITE DATA

All of the federal users of weather satellites we contacted were concerned about the impact of commercialization on the price of weather satellite data. Most were also concerned about service. The draft RFP issued in October 1983 recognized several of these concerns. However, the transfer process did not proceed far enough to determine the impact of commercialization on prices or whether commercialization agreements would have ensured contractor performance satisfactory to all federal users. To obtain the views of federal users of weather satellites, we spoke with officials from seven agencies: the Bureau of Land Management, Bureau of Reclamation, Coast Guard, Federal Aviation Administration, National Weather Service, Environmental Research Laboratories in NOAA, and the Smithsonian Institution. (See app. I for individual descriptions of the ways federal agencies use weather satellite data.)

Background on federal users of weather satellite data

Federal agencies obtain imagery, measurements of the environment, and other data from the weather satellites. The following table shows various ways federal users[1] obtained satellite data in fiscal year 1983.

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[1]Excludes national security agencies.

Federal department	Direct broadcast[a] receiving stations	Telephone transmission subscribers	Data collection systems platforms		Archived data[b] product deliveries
			G[c]	P[d]	
Agriculture			199		770
Commerce	17	56	436	96	14,077
Interior			1,443		47
Transportation	4	25		10	159
NASA	5	6			9,820
Other	1	4	85	17	8
Total	27	91	2,163	123	24,881

[a]Direct, real-time satellite transmissions of images, environmental data, and search and rescue distress signals and delayed transmissions of processed data.

[b]Includes pictures, tapes, and other products, such as charts.

[c]Geostationary satellites.

[d]Polar orbiting satellites. Figures show number of platform years. For example, two buoys used for 6 months each equal 1 platform year.

Federal users pay NOAA only for archived data[2] and pay a French firm for use of the data collection system on board the polar orbiting weather satellites. However, each agency buys its own equipment to receive and use the satellite data and data collection platforms, such as buoys and other remote sensors.

The federal agencies we contacted use the satellite data in various activities. The largest user of weather satellite data, NOAA's National Weather Service, uses the data to provide weather forecasts to the general public and to issue warnings against such destructive natural events as hurricanes, tornadoes, and floods. Other federal applications include protecting life and property through forecasting hazardous weather for pilots, monitoring icebergs, and locating aviation or boating accident victims; managing public resources under jurisdiction of the federal government, such as fire protection activities on lands managed by the Bureau of Land Management; monitoring the condition of the environment, such as detecting solar disturbances by the NOAA Space Environment Services Center and collecting weather information from remote locations; and advancing scientific knowledge about the atmosphere, oceans, and lands, such as the Smithsonian Institution's monitoring of volcanic eruptions.

[2]A small connection and yearly maintenance fee is also collected for a hookup allowing a user to receive telephone line transmission of geostationary satellite data. The data are free.

Concerns of federal users

All of the federal users of weather satellites we contacted had some reservations about the possible consequences of selling the satellites to the private sector. In general, the concerns focused on (1) increased costs of satellite data and (2) decreased data and services under private ownership. All federal users expected costs for satellite data to increase and expected problems with the data and services provided by a private owner. Officials in six of the seven agencies we contacted also believed satellite research and development might suffer.

Federal officials mentioned several reasons for these concerns about commercialization. Four federal users attributed possible cost increases and changes to or discontinuation of data or services (types of data collected, data archives, and methods for providing data) to the need for a private owner to make a profit. Three believed the administrative process of buying satellite data from a private firm would be more costly. Two also believed that additional costs for data processing equipment and software would result from changes to the format of the data provided to federal agencies. Five users expected poorer service (timeliness and data quality problems), particularly during a transition period, because a private firm would be less responsive to the needs of federal agencies and not have the technical skills and expertise or working relationships with federal agencies.

Federal officials in all of the seven federal agencies we contacted believed that specific terms and conditions were needed on the quality and timeliness of data delivered to federal users. They explained that such terms and conditions were needed to prevent deterioration of quality and timeliness or provide incentives for high quality services. Officials of the National Weather Service responsible for issuing forecasts of hurricanes and severe storms were especially concerned that the sale of the weather satellites be made on terms which assured their continued access to timely, useful data.

Federal officials in four agencies believed that advances in weather satellite technology might be slowed because of private ownership. Weather Service officials, for example, believed that a private operator would not be as familiar with National Weather Service needs as a government operator.

RFP treatment of
federal users' concerns

The RFP proposed by the Department of Commerce addressed many of the concerns expressed by federal users of weather satellites. The RFP required the private operator to provide present services such as direct broadcasting, data collection services, and relaying search and rescue distress signals. The government was to receive all satellite data from the private operator. Federal agencies would have continued to receive, free of charge, the

services they now receive from the National Weather Service. The RFP specified what items were to be delivered, in what manner, and at what times.

The government was to continue present services such as the telephone line transmission of geostationary satellite data, archives, and free international exchange of satellite data. Federal research and development programs were to continue, and test flights of new sensors and equipment on operational satellites were anticipated. For example, the search and rescue equipment on the most recent polar weather satellite is part of an international cooperative research and development program. The government wanted similar arrangements for flights aboard commercial satellites.

One concern of federal users of weather satellites was not satisfied by the RFP. Some cost increases for data and services would have been likely because the data collection systems were to be fully commercialized services. Currently, users of the polar orbiters' data collection system service pay a French firm for processing data. NOAA processes and provides the data from the geostationary satellites' data collection system free of charge. Under commercialization, federal users would have been expected to pay for such services.

FOREIGN USERS OF WEATHER SATELLITE DATA

How other countries receive U.S. weather satellite data

U.S. weather satellite data is shared with other countries in several ways: through a United Nation's exchange system, via direct satellite transmissions of sensor readings and other information, and by relaying transmissions of data collection platforms located in oceans and rivers. The most extensive method of satellite data distribution involves the United Nations' World Meteorological Organization. Most nations participate in the Organization's Global Telecommunications System, a communications system for sharing weather information worldwide in a program called the World Weather Watch. The United States and other nations that operate weather satellites include satellite data in the system. U.S. weather satellite data are also transmitted directly to ground stations in other nations. As of February 1983, NOAA reported that 120 nations owned more than 800 ground stations for the direct reception of U.S. weather satellite data. Foreign countries also use the satellites' data collection systems.

How other countries use U.S. weather satellite data

The U.S. weather satellites are important to other countries for predicting severe weather, for improving the accuracy of longer term weather forecasting, and for supplying weather

information for areas not covered by more traditional data sources. One of the most critical uses of the weather satellites is in the Caribbean where a geostationary satellite provides information for predicting and tracking life-threatening hurricanes. The Director of the Barbados weather service said that without direct readout from the satellite he could not provide adequate hurricane warnings. The Director pointed out that time for preparation before a hurricane is critical for saving lives and property. He also said that hurricane warnings have more credibility with the general population when satellite imagery can be viewed on television.

Satellite data are also important for more general weather forecasting. The Director of the weather service in Barbados said that the polar orbiting satellite is essential for weather forecasts in the Caribbean. In general, the greater the number of reporting points for temperature, wind speed, and other environmental phenomena, the more accurate a weather forecast will be. In recent years, there have been too few ships in the Atlantic, east of the Caribbean, acting as reporting points, so that Barbados and other Caribbean nations depend on the satellite data. According to the Director of the weather service in Brazil, the satellites are crucial in the Southern Hemisphere to track fronts and for the quantitative evaluation of fronts. Weather officials in Japan and Thailand told us that the U.S. weather satellites made important contributions to longer term forecasts and to monitoring ocean areas.

The satellites serve several other useful purposes, such as providing hydrographic data, contributing data to international weather research projects, aiding international search and rescue missions, and conducting crop inventories. For example:

--Brazilian weather officials said that without the transmission via the geostationary weather satellites of information from data collection platforms on the rivers, it would be difficult to learn about flooding and droughts in remote regions of the country.

--The World Meteorological Organization operates research programs to promote better understanding of the environment. The U.S. weather satellites provided data for the First Global Atmospheric Research Program of 1979, a coordinated effort of several World Meteorological Organization members to solve some of the major questions about the atmosphere for long-term weather prediction.

--The latest U.S. polar orbiting satellite, launched in March 1983, has the capability to locate emergency broadcasts of aircraft and oceangoing vessels in trouble. An example of the international cooperation involved in satellite search and rescue efforts occurred in 1982 when a Soviet weather satellite picked up the emergency transmitter signal of a downed aircraft in

Canada. The Soviets relayed the location of the aircraft via the U.S. Coast Guard.

--The United Nations' Food and Agriculture Organization uses the U.S. polar orbiter satellites for broad-scale views of natural resources in short time periods. The Organization's Remote Sensing Center provides technical assistance and training for many nations using these data.

--The Agency for International Development uses the weather satellites for a disaster early warning system which indicates possible food shortages triggered by climatic changes. This enhanced capacity to identify and evaluate disaster conditions provides greater lead time for planning food assistance strategies. The early warning information can be provided 30 to 60 days prior to the harvest of grain crops or 3 to 6 months prior to an actual food shortage. According to Agency for International Development officials, the better prepared a country is for disaster, the less probability there is of death, suffering, and property damage.

The United States benefits from the international sharing of weather information

Weather data have been shared freely among nations for more than a century. Besides ground and upper air observations obtained through the World Meteorological Organization system, the United States can receive direct readouts from other nations' weather satellites. Western Europe, Japan, and India have geostationary satellites and the Soviet Union has a polar orbiting satellite. The United States can obtain data directly from each of them. The European, Japanese, and United States satellites share a common Weather Facsimile transmission frequency allowing for the sharing of weather data.

Foreign nations have also contributed sensors and technical support for U.S. polar orbiting satellites. The United Kingdom provides the stratospheric sounding unit, a temperature-reading device on board the polar orbiters, at no cost to the United States. France and Canada jointly provide the search and rescue instrument. France provides the data collection system on board the polar orbiting satellites at no cost to the United States. The French space agency also acts as a backup to NASA after the launch of a polar orbiter. The French agency has the capability to receive soundings and take command of the satellite.

The United States benefits from free international exchange of weather data by getting

--worldwide information needed for more accurate longer range predictions of U.S. weather,

--overseas weather information to support its worldwide commercial and defense interests, and

--data it could otherwise acquire only by spending additional funds for observations in foreign areas and by receiving observations that might be impossible to make without foreign cooperation.

Concerns of foreign users

The administration's March 1983 decision to proceed with the commercialization of the weather satellites caused various countries to express concern about its possible consequences. In addition, representatives of the foreign weather services we met with had concerns. The concerns centered mainly around (1) charges for satellite data to the World Meteorological Organization, (2) the termination of free transmission of compatible data to foreign ground stations, and (3) disruptions in international cooperation.

The United Kingdom's Department of Industry prepared a position paper on the proposed commercialization, urging continued international cooperation and free data exchange. The United Kingdom paper stated that:

"The UK considers that any scheme for commercialization of the provision of meteorological satellites in the USA should take account of existing and potential international agreements to provide instruments as contributions towards the US polar-orbiting satellite system. There are doubts regarding the feasibility of such agreements under the new system. These uncertainties are already causing difficulties and delays in securing financial authority for UK participation in the proposed Advanced Microwave Sounding Unit."

. . . . .

"The UK strongly recommends that any internal rearrangements within the USA should safeguard the existing principle that no charge be made for meteorological observations provided to other national meteorological services. This should extend to data directly broadcast by meteorological satellites and the derived data (e.g. temperatures, winds) exchanged through normal meteorological telecommunications channels. No contrary decision should be made without a full examination of the likely consequences of charges being made for all meteorological observations on a world-wide basis."

The Canadian Government prepared a paper indicating concern about the sale as follows:

> "Canada's data collection activity, especially in the north, at least equates with the U.S. contribution of satellite acquired data. Thus, on a bilateral basis, both countries make essential contributions to weather prediction in North America. It is our hope that the free exchange of weather information will continue between Canada and the USA, and on a global basis."

In June 1983, the World Meteorological Organization held its quadrennial conference in Geneva. The Organization reaffirmed the principle that "data and products available within the World Weather Watch system should be exchanged freely and without charges between members. . . ." Another principle stated that "meteorological satellites, both polar orbiting and geostationary, in their observation, data collection and dissemination roles, are of fundamental importance for the operation of the WWW [World Weather Watch]."

The RFP would have continued international arrangements for use of the weather satellites

The cancelled RFP for the weather satellites addressed most foreign concerns about the weather satellites. The RFP would have required that the U.S. government review and approve or disapprove decisions of the private operator on matters and issues involving foreign policy and international obligations and that:

--The private operator must continue the functions of the foreign sensors provided by France, Canada, and the United Kingdom, or replace those instruments.

--The private operator provide the same volume and quality of data to the World Meteorological Organization network via NOAA as is currently provided.

--The private operator continue the current volume and quality of weather satellite data to foreign ground stations via direct readout.

--The U.S. government continue to archive the data.

Despite these RFP provisions, representatives of weather services in Argentina, Barbados, and Brazil told us that commercialization reduced the prospects for continued, long-term, free exchange of weather information and made international cooperation more difficult. These officials said that continued free access to data in the future would be less certain with the

commercial operation of the satellites. They said they preferred continued operation by a government agency.

NONFEDERAL USERS OF WEATHER SATELLITE DATA

Ten of the 14 nonfederal weather satellite users we contacted were opposed to commercialization of these satellites at this time.[3] Even those nonfederal users that were not opposed to commercialization had several concerns which they believed should be addressed by the government before transferring the systems to the private sector. Nearly all of the users, whether or not they opposed commercialization, were concerned about the danger of a private owner having a monopoly on the supply of weather satellite data with a resulting negative impact on prices, service, and research. Some users indicated that commercialization, with proper government regulation, could benefit both public and private users.

Background on nonfederal users of weather satellite data

Nonfederal users obtain weather satellite data from either the geostationary or polar orbiting satellites. Users obtain real-time data from the satellites if they have their own receiving stations, referred to as direct readout stations. Users obtain near real-time geostationary satellite data via telephone line. Archived data are obtained from NOAA's Satellite Data Services Division or by subscription to NOAA's Weather Facsimile system. Nonfederal entities also use the weather satellites' data collection systems. The following table shows the number of nonfederal users of the various forms of weather satellite data.

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[3]The views we obtained on commercialization were those of organization officials and may not represent formal positions of the organizations themselves.

Nonfederal Users of Weather Satellite Data

	Number of nonfederal users
Direct readout stations	208 (as of Jan. 1, 1983)
Subscribers to geostationary satellite telephone line transmission[a]	73 (as of Jan. 17, 1983)
Archived data buyers	724 (from Oct. 1, 1982, to Aug. 19, 1983)
Weather facsimile subscribers	69 (as of May 31, 1983)
Data collection system subscribers	311 (as of Aug. 1, 1983)

[a]These are primary subscribers; an unknown number of other users receive a secondary transmission of data from the primary subscribers.

Nonfederal users pay the government only for the ability to receive telephone line transmissions of geostationary satellite data and archived data. To obtain the geostationary satellite data, a user pays an initial fee of $1,000 and a yearly service fee of $100. For archived data, user fees, which run up to $175 for an image and $154 for a computer tape, depending on the product purchased. The following table shows the numbers and dollar amounts of archived computer tapes and photographic products sold by NOAA to nonfederal U.S. users in fiscal years 1981 through August 19, 1983.

Summary of NOAA's Archived Weather Satellite Data Sales FY 1981-83

	Photographic products		Computer tapes		
FY	No.	Dollar amount	No.	Dollar amount	Total dollar amount
1981	13,125	$71,524	671	$49,649	$121,173
1982	10,389	109,253	467	61,432	170,685
1983 (to Aug. 19)	7,974	93,678	475	64,656	158,334

Weather satellite data are used in the nonfederal sector in a wide variety of ways by a wide variety of users. For example:

--State and local governments use satellite data to issue storm and freeze warnings to their residents to protect lives, homes, farms, and businesses.

--Television and radio stations use satellite data in preparing weather forecasts which are broadcast to the public.

--Private companies use weather satellite data for numerous purposes, such as to route airplanes and transoceanic ships, plan construction of offshore oil exploration projects, develop agricultural crop production estimates, plan agricultural irrigation and pesticide spraying activities, and predict demand for natural gas and electrical power.

--Colleges and universities use satellite data in performing basic and applied research for agriculture, water management, data processing, and other projects.

--Private individuals use satellite data (via their own receiving stations) to obtain up-to-the-minute weather information for personal use.

Concerns of nonfederal users

As the table on page 38 shows, all 14 nonfederal users we spoke with expressed some concern about the proposed commercialization of the weather satellite systems. Nearly all users were concerned that commercialization might create a monopoly for the single, private owner of the entire satellite system. Users were concerned that the private owner would not only have complete control of the "raw" satellite data but, if unchecked, would eventually have a monopoly over the value-added service market.

Many of the users' other concerns--unreasonable and discriminatory data prices, discriminatory data access, and decreases in quality of data and service--were directly related to the potential for monopoly. These users said that the creation of a monopoly with power to set discriminatory or unreasonable prices and discriminatory sale policies violated the principles of free enterprise and open competition. They also explained that decreases in quality of data and service could have disastrous effects; for example, if satellite data are disrupted or of such poor quality that a freeze in a citrus region or a hurricane off the coast is not accurately forecast, lives and millions of dollars in property could be lost. Four users expressed further concern that if a monopoly existed, the government and taxpayers would incur costs to regulate and audit the private owner in addition to the costs the government would have to pay to receive the data.

Four of the 14 users we contacted said that government regulation could control the problem that a monopoly on satellite data could cause. They believed that, even if it had a monopoly, the private owner would charge reasonable prices and provide acceptable service because to do otherwise would severely limit sales

Summary of Nonfederal Weather Satellite Users' Opinions and Concerns Regarding Commercialization

User's organization[a]	Opinion regarding commercialization	Would commercializing weather satellites create problems in the following areas? Monopoly	Discriminatory unreasonable pricing	Discriminatory access to data	Continuity/ quality of data or service	Additional cost to government/ taxpayers	Decrease in research and development
Earth Satellite Corp.	Not opposed	Yes	Yes	Yes	No	No	Yes
Eastern Airlines	Opposed	Yes	Yes	Yes	Yes	[illegible]	Yes
Environmental Satellite Data, Inc.	Opposed	Yes	Yes	Yes	Yes	No	Yes
Florida Weather Service, Inc.	Opposed	Yes	Yes	Yes	Yes	Yes	Yes
Global Weather Dynamics, Inc.	Opposed	Yes	Yes	Yes	Yes	Yes	Yes
Gordon Barnes Weather Service	Not opposed	No	No	Yes	No	Yes	No
Gulf Coast Weather Service and WTVT Weather Service	Not opposed	No	Yes	Yes	Yes	No	Yes
Harris Corp.	Not opposed	Yes	Yes	Yes	Yes	Yes	Yes
National Farmers Union	Opposed	Yes	Yes	Yes	Yes	Yes	Yes
Nowcasting, Inc.	Opposed	Yes	Yes	Yes	Yes	Yes	No
Oceanroutes, Inc.	Opposed	Yes	Yes	Yes	Yes	Yes	Yes
Pacific Gas and Electric Company	Opposed	Yes	Yes	Yes	Yes	Yes	No
Robert Ryan, Meteorologist	Opposed	Yes	Yes	Yes	Yes	Yes	No
University of Florida	Opposed	Yes	Yes	Yes	Yes	Yes	Yes

[a]The views expressed were those of organization officials and may not represent formal positions of the organizations themselves.

and profits. One user believed that a private owner could not adequately serve all end users throughout the nation and, therefore, would not monopolize the value-added industry.

Examples of other areas of concern follow:

--Ten users expressed concern that under private ownership, weather satellite research and development would suffer. They believed that a private owner would not have the resources or incentives to undertake the expensive, high-risk research and development necessary for continued technological advances in satellite sensing and data processing. One user questioned whether the federal government would or should continue to do expensive research and development only to have the results turned over to a single, private company.

--Twelve users believed that weather information (including satellite data) is a public good and that providing this information should therefore be a governmental function. They also told us they were satisfied with the data and service provided by the government; they viewed commercialization as resulting in few benefits and many potential problems to the government and users.

--Twelve users also were concerned that the public investtment in the satellites would not be recovered in a sale and that commercialization would increase government costs. Taxpayers, they told us, have spent millions of dollars to develop the satellite systems to their present status. These users believed that commercialization would undoubtedly lead to taxpayers paying, directly or indirectly, for the data. They believed that having taxpayers pay a private company's profit margin for data coming from the taxpayers' own investment would not be fair.

Potential benefits cited by nonfederal weather satellite users

Six of the nonfederal users we contacted said that private ownership of the weather satellites might provide some benefits because a private owner's profit motive would result in lower costs and better service to customers. According to these users, a private owner would be better able to

--quickly respond to the individual needs of users,

--quickly implement advances in satellite and data processing technology,

--efficiently and effectively operate the satellite systems,

--improve the marketing of data products, and

--save the government and taxpayers money in the long run.

One user believed that commercialization would be a first step toward streamlining and reducing the National Weather Service's operations. This user believed that the private sector is better able to provide localized weather information and services to the public and, furthermore, that forecasters currently employed by the National Weather Service would be better utilized if they were employed by private companies providing such local weather services.

Nonfederal users' suggestions for commercialization terms and conditions

The table on page 41 summarizes the nonfederal users' suggestions for terms and conditions the government should have required if commercialization of the weather satellites had occurred. Most users indicated that these suggested terms and conditions should have been clearly defined and explained in the government's request for proposals for the weather satellite systems.

Summary of Nonfederal Users' Suggestions for Terms and Conditions for Commercialization of Weather Satellites

Nonfederal user's organization[a]	Ensure nondiscriminatory/ reasonable prices	Ensure equal access to data	Establish performance standards[b]	Prohibit owner from value-added industry	Regulate similar to public utility
Earth Satellite Corp.	Yes	Yes	Yes	Yes	No
Eastern Airlines	Yes	Yes	Yes	No	Yes
Environmental Satellite Data, Inc.	Yes	Yes	Yes	Yes	No
Global Weather Dynamics, Inc.	Yes	Yes	No	Yes	Yes
Gordon Barnes Weather Sevice	Yes	Yes	Yes	No	Yes
Gulf Coast Weather Service and WTVT Weather Service	Yes	Yes	Yes	No	Yes
Harris Corp.	Yes	Yes	Yes	Yes	No
Nowcasting, Inc.	Yes	Yes	Yes	Yes	Yes
Oceanroutes, Inc.	Yes	Yes	Yes	Yes	No
Pacific Gas and Elec. Co.	Yes	Yes	Yes	No	Yes
Robert Ryan, Meteorologist	Yes	Yes	Yes	No	Yes
University of Florida	Yes	Yes	Yes	No	No

[a]Two users did not express any views on sales terms because they said that they were opposed to commercialization on any terms. Also, the views expressed were those of organization officials and may not represent formal positions of the organizations themselves.

[b]This column includes performance standards for continuity and quality of data and service, fulfillment of international agreements, fulfillment of federal agencies' and national security requirements, and research and development requirements.

As the table shows, nearly all nonfederal users who offered suggestions told us that the government should

--ensure nondiscriminatory and reasonable data prices for all users,

--ensure equal access to data by all users, and

--establish performance standards which the private owner must meet.

Six users believed that the private owner should be prohibited from performing value-added services. They explained that a private owner with complete control of the data could destroy all competitors in the value-added industry. On the other hand, some of the users said that barring the owner from the value-added industry would lead to many potential private owners not bidding for the weather satellite systems. Seven users told us that the satellite owner should be regulated by the government in the same manner as public utilities.

How the RFP addressed nonfederal users concerns

The cancelled weather satellite RFP addressed most of the concerns raised by nonfederal domestic users of weather satellites. The RFP stated that the private operator was to provide all satellite data to the U.S. government, which would have continued to process and distribute that data and its products to government agencies and private sector organizations. The RFP indicated that the government would have continued current services to the private sector, such as telephone line transmission of geostationary satellite data and archiving data, and required the private operator to continue direct broadcasting of sensor data and weather facsimile information to privately owned receiving stations. A private owner would have been expected to meet the quality standards already in use for current weather satellite systems. The government would have continued to do research and development on weather satellite technology.

On the other hand, the private operator would have been permitted to enter the value-added business for weather data and charge a fee for the use of the weather satellites' data collection systems. The communications channels on these systems are rapidly becoming fully subscribed. Present users of these systems might have faced price increases under commercial operation.

APPENDIX I

HOW FEDERAL AGENCIES USE LANDSAT AND THE WEATHER SATELLITES

DEPARTMENT OF AGRICULTURE

Foreign Agricultural Service

The Foreign Agricultural Service monitors and forecasts crop production on a global basis and disseminates the information to the general public. The crop forecasts are based on a variety of information, such as U.S. embassy reports, press reports, foreign government publications, trade and weather reports, and land and weather satellite data. The Service's primary means of estimating foreign crop production is through onsite inspections by U.S. embassy personnel. Satellite data are used as a supplement to refine the estimates and make them more reliable. In certain countries, however, satellite data are the primary source of information because the travel of U.S. embassy personnel is restricted or the area of coverage is too large to use embassy personnel. For instance, the Soviet Union restricts onsite inspections; China and Brazil have extensive crop areas.

Service crop production analysts told us that Landsat is a useful tool for estimating crop production because it provides a relatively high-resolution image of crops. The weather satellites are also useful to the Service because they provide continuous time comparisons of the same area. Service officials told us that Landsat is not expected to replace ground observation as the primary information-gathering tool in the foreseeable future because the science of interpreting Landsat images is not precise. Vegetation is shown on images as "red," and the intensity of the color indicates the potential yield of the vegetation. Uncertainty exits, however, in estimating the yield based on the color intensity. Officials said that the Foreign Agricultural Service does not plan to increase its use of satellite data.

Statistical Reporting Service

The Statistical Reporting Service is responsible for preparing domestic agricultural statistics, including estimates of domestic crop production. The Service, like the Foreign Agricultural Service, uses onsite farm inspections as its primary tool for estimating crop production. Over the years, the Service has conducted or participated in a number of studies to assess the usefulness of Landsat. Generally, the studies' results have shown that Landsat is an effective tool for classifying land into various categories, such as rangeland, cultivated lands, and irrigated lands. Currently, the Service is using Landsat data on an experimental basis in conjunction with the traditional ground sources to estimate major crops in Arkansas, Colorado, Illinois, Iowa,

Kansas, Missouri, and Oklahoma. The Service plans to expand coverage to other states if funds can be obtained for such purposes. The Research Division Director told us that he believes Landsat is a valuable tool in crop estimating and the data provided often result in adjustments to estimates derived from traditional sources.

Soil Conservation Service

The Soil Conservation Service is responsible for developing and carrying out a national soil and water conservation program. Generally, the Service carries out its program through onsite, labor-intensive investigations by field office personnel. However, the Service uses Landsat on an experimental basis in four states as an aid to field personnel engaged in soil surveys and in two states as an aid in conducting land-cover studies. The Service makes soil surveys to identify and catalog specific types of soils throughout the nation. Landsat is used to identify soils with similar composition. Field personnel then take soil samples for analysis to determine whether the soils are identical. Land-cover studies involve identifying how the land is being used, such as for crops or as pasture, forest, or urban areas.

Although Landsat is currently only being used to a limited extent, the Service believes Landsat holds considerable promise in conducting soil surveys, resource inventories, and watershed analysis. A Service official told us that Landsat will become an important tool as high technology is substituted for the high cost of labor.

Agricultural Research Service

The Agricultural Research Service is the primary research arm of the Department of Agriculture. It uses Landsat to examine how remote sensing technology can be used to provide information about the ecological balance of agricultural areas. In addition, the Service is developing a computer program to eliminate atmospheric interference in Landsat images.

The Service conducts basic and applied research in support of the operational programs of other departmental agencies, such as the Foreign Agricultural Service and the Statistical Reporting Service. Examples of research efforts involving weather satellite data include

--determining water use rates by plants and crops,

--determining aridity indexes of land areas, and

--developing a computer program to eliminate cloud cover from satellite images.

A Service official told us that the Service plans to increase its use of Landsat data for assessing crop conditions and related variables. He also stated that weather satellite data hold considerable promise and that much of the Service's remote sensing research is evolving in that direction.

Forest Service

The Forest Service promotes and manages national forests. Its responsibilities include protecting and improving the quality of air, water, soil, and natural beauty of the forests and to assure balanced uses of forest products by private enterprise.

The Service currently uses Landsat satellite data on an experimental basis to inventory the renewable resources of Alaska and to conduct nationwide land-use surveys. Service officials believe that Landsat's potential is great because of the vast areas that can be covered at relatively low cost for mapping, surveying, and land management. For example, with Landsat data, nationwide, land-use surveys are now possible annually instead of every 10 years.

The Service uses the geostationary satellites' data collection system to collect data on wind, temperature, humidity, soil temperature, and moisture from its Remote Automated Weather Stations to prepare input for a national fire-rating system. The data collection system is less expensive than transmitting information by telephone line, the system it is replacing. The fire rating gives an indication of likely fire danger areas for planning purposes, i.e., for staging and moving people to fight fires. According to the Service's National Fire Planning Specialist, the Service is dependent on the Remote Automated Weather Stations' data for improving the accuracy of its fire danger model.

If the Service's use of Landsat in land management and resource assessment is successful, it plans to expand its use of satellite data into areas such as locating the outbreak of various forest pests and in mapping.

DEPARTMENT OF THE ARMY

Corps of Engineers (Civil Works)

The Corps of Engineers uses both the Landsat and weather satellite systems to support its natural disaster preparedness mission. Landsat data are used to, among other things,

--determine land cover as an aid in estimating the runoff potential of watersheds,

--produce economic studies of the impact different flood levels would have on cities and communities, and

--aid in planning mitigation efforts for presidentially declared major disaster areas.

According to Corps officials, these and other activities require the frequency and breadth of coverage which Landsat offers.

The Corps uses the geostationary satellites' data collection platforms and weather facsimile communication systems to obtain information on natural disasters. Satellite data are particularly important in flood control, which requires near real-time data.

DEPARTMENT OF COMMERCE

National Weather Service

The Department of Commerce's National Weather Service is the primary federal user of weather satellite data. The Service uses satellite data to provide general weather forecasts and warnings of severe weather such as hurricanes, tornadoes, and floods. According to Service officials, the weather satellites are particularly valuable for forecasting severe weather and for making long-term weather forecasts. The geostationary satellites are uniquely suited to detecting the formation of severe storms and hurricanes and tracking the movements of hurricanes through the Atlantic Ocean and coastal areas of the United States. The polar orbiting satellites are particularly useful in producing long-term U.S. forecasts because they provide data not otherwise available on the Pacific Ocean, where most of the nation's weather originates.

The Service uses two types of data from the geostationary satellites: visual images and quantitative environmental data. The visual images are supplied by two specialized instruments which remotely sense the earth's surface. The images have several uses, including locating actual or potential severe storms, following cloud motion, and determining wind speed and direction. Quantitative environmental data is provided by other sensors and by the geostationary satellites' data collection system which collects and relays environmental data obtained by remotely located platforms, such as seismology and tide guage platforms, data buoys, river and rain guages, aircraft, and automatic weather stations. For example, the seismology and tide guage platforms detect tsunamis (a very large ocean wave caused by an underwater earthquake or volcanic eruption) and provide early warning information to the Service's Tsunami Warning System Program. Data buoys provide measurements of ocean weather in areas away from coastal weather forecasting facilities or outside of shipping lanes. River and rain guages provide a near-instantaneous source of data on rainfall and runoff that is used in flood forecasting. A variety of other data platforms supply a continuous source of information to help the Service provide weather forecasts and severe weather warnings to the public.

The National Weather Service uses both quantitative data and image data from the polar-orbiting satellites. The quantitative data are used to improve the base for the Service's numerical weather prediction models. The data are obtained from a variety of sensors as well as through the data collection system. The data collection system is a French-produced system capable of collecting data from remotely located platforms and recording the location of those platforms at the time data were received from them. The system provides information such as the direction of ocean currents, rainfall amounts, surface winds and pressures, and subsurface ocean temperatures. Image data are obtained through other sensors and are used for a variety of purposes, such as

--producing global cloud maps to aid in analyzing weather patterns,

--analyzing ice conditions over ocean areas and the Great Lakes, and

--estimating snow pack in watersheds and predicting spring melt.

Environmental Research Laboratories

The Environmental Research Laboratories use weather satellites in various programs, such as analyzing convective (summertime) clouds and the precipitation processes in them, improving weather forecasting, studying cases of severe weather, monitoring solar variations not detectable from the ground, planning hurricane research flights, evaluating monsoons, studying ice conditions, and providing sea surface temperature maps to aid in understanding climate.

Most Environmental Research Laboratories expect to increase their use of satellite data, especially as technology advances. Some future uses include studying x-ray images of the sun to better forecast geomagnetic disturbances and constructing global wind circulation models.

DEPARTMENT OF ENERGY

The Department of Energy, through contracts with the National Laboratories and other research establishments, uses Landsat data in an increasing number of research applications. Specificaliy, Landsat data have been used to site energy-generating facilities, develop explorational techniques for energy resources, and characterize potential nuclear waste repository sites. Satellite images are used to locate geographical areas such as salt domes and granite formations suitable for dumping nuclear waste.

The Department of Energy will continue to perform research on the possible uses of Landsat in both energy and environmental research applications. An Energy official stated that a growth rate in the use of Landsat data of up to 20 percent per year for the next 5 years is possible. This estimate is dependent upon continuity and reliability in providing Landsat services.

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency has experimented with Landsat data to monitor air and water quality. For example, Landsat data have been used to classify land uses for monitoring air quality and to monitor the acidity of lakes. The Agency uses Landsat data experimentally because of resolution limitations. For small areas, the Agency believes that aerial photography is better than satellite data because it offers better resolution and can be obtained faster than satellite data. The Agency does not expect to increase its use of satellite data without improvement in the data resolution.

DEPARTMENT OF THE INTERIOR

United States Geological Survey

Current U.S. Geological Survey uses of Landsat data include (1) mapping of geologic structures to investigate likely occurrences of minerals and fossil fuels and to assess geological hazards, (2) geologic analysis in support of nuclear disposal program, (3) surface water inventories in the conterminous United States and Alaska, (4) national land-use/land-cover mapping, (5) preparing image maps in poorly mapped regions of Antarctica, the Middle East, and other regions to support international cooperative programs, (6) monitoring coastal shoreline changes, (7) detecting and monitoring oil slicks, (8) assessing and monitoring water quality and turbidity, (9) monitoring snow cover and melt in watersheds and hydroelectric dams for use in predicting runoff calculations, and (10) assessing the impact of floods and other natural disasters.

As uses of satellite data become more routine and integrated into the Geological Survey's programs, usage is expected to increase. With possible advancements in satellite sensor technology, telecommunications, computer processing technologies, and information extraction methods, it is expected that use of satellite data will increase many times over its present use, both operationally and in research.

Bureau of Land Management

The Bureau of Land Management uses both Landsat and weather satellite data in managing over 300 million acres of public lands. Weather satellite data are used in wildfire management for

lightning detection (lightning causes 60 percent of all major fires on public lands), mapping of types of burnable material, and calculating likely fire intensity and spread. These data help management make a decision on suppressing the fire or permitting it to burn itself out. Landsat data are also used in resource inventories (environmental assessments of oil and gas leases and mining), boundary location, trespass and easement determination (settlement of disputed boundaries, illegal easements, mining trespassers), geological mapping (glacier ice deposits, bedrock documentation, and minerals potential), and renewable resource condition assessment (monitoring rangeland for overgrazing, estimating numbers of grazing animals, determining whether to lease grazing lands).

Bureau officials expect to expand their use of satellite data in such areas as updating inventories, supporting evolving range-monitoring programs, creating geographic data bases for the Bureau's Alaska lands, monitoring dam safety, and collecting data for more accurate river and streamflow forecasts.

Bureau of Reclamation

The Bureau of Reclamation uses both weather satellite and Landsat data in (1) developing cloud seeding technology for increasing the nation's fresh water supplies, (2) surveying for wind energy sites, (3) investigating cathodic protection methods (pipe corrosion), (4) studying water evaporation on lakes, and (4) monitoring oil spill movements. In addition, the Bureau uses satellite data for (1) assessing uses of lands which may affect or change water resources in the area, analyzing geological structures (faults) which may affect the safety of a dam, canal, or other water structure, (2) measuring water quality and surface area of waters over large geographic areas, and (3) measuring the use of irrigation waters.

The Bureau expects its future uses of Landsat data to increase as satellite capabilities are developed and to continue ongoing programs in the remote sensing area.

Fish and Wildlife Service

The Fish and Wildlife Service uses satellites mostly as an auxilary data source for habitat mapping for national wildlife refuge planning, and for water resource project impact evaluations. For example, satellite data are used to monitor snow melt on Arctic goose breeding grounds to predict nesting success and regulate bird hunting. The Service's officials said that the agency will increase its use of satellites if improvements are made in resolution. Future uses include updating the National Wetlands inventory and continuing ongoing applications.

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National Park Service

The National Park Service uses Landsat data to survey land cover, land uses, and geology for resource management and planning. For instance, one major application is for fire fuels modeling and fire behavior modeling. From these data, fire hazard maps are created and aid in determining whether a fire should be suppressed or allowed to burn. Landsat data are also used to determine how commercial activities, such as mining and animal grazing, affect land areas and to assess the habitat of endangered species, such as the grizzly bear. Other uses include evaluating the effects of man-made interference with water resources in the Everglades and for archeological investigations. In addition to continuing present programs, the Service expects increases in satellite use, including updating data bases on every large park every 10 to 15 years, monitoring how facilities (such as powerplants) in national parks use coal and how parks are affected by its use, and updating the quality of park maps to include natural history and trail guides.

Bureau of Indian Affairs

The Bureau of Indian Affairs uses Landsat data on an experimental basis to provide current land-use and land-cover information on Indian lands. The pilot project is to determine potential irrigable lands and to develop a rangeland trend and condition monitoring system. The Bureau expects its use of satellite data to increase in the future. In addition to land-use and land-cover applications, future uses of satellite data include determining the extent of natural resources on Indian lands, such as forests, rangeland, water, fish, wildlife, and minerals. The Bureau also plans a pilot study to determine the usefulness of using weather satellite data for monitoring and assessing drought conditions.

Bureau of Mines

The Bureau of Mines has used Landsat data on an experimental basis to detect the expansion of mines, monitor waste dumping to ensure proper disposal of waste from mines, and study the wilderness studies.

The Bureau has found Landsat especially useful in detecting faults which can cause mine cave-ins. Once faults are identified, the Bureau alerts mining companies so that steps can be taken to avoid mining accidents, loss of life, and production. Also, the Bureau provides information to the Mine Safety and Health Administration within the Department of Labor for use in safety and health enforcement activities.

Landsat use is expected to expand as new geographic areas are examined and other areas are reexamined to detect geological changes. Computerized evaluation of ground hazards will be a

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major development. Instead of manually examining images to identify faults, computers will be used in the future to analyze Landsat data. Long-term goals include developing hazards maps in order to forecast potential problems in mined-out areas and monitoring waste piles and dams.

Office of Surface Mining
Reclamation and Enforcement

The Office of Surface Mining Reclamation and Enforcement uses Landsat data to make decisions on issuing mining permits. Landsat imagery is used to detect alluvial areas and determine the potential success of revegetation. Alluvial valley floors are geographical areas that are naturally watered with no need for irrigation and are protected to retain crop productivity. The Office expects its future use of Landsat to increase if the quality of data improves. For example, the Office is responsible for detecting, controlling, and extinguishing mine fires. Landsat's infrared capability could be used in this effort if the current image resolution were improved. Officials of the Office said that increased precision of Landsat images would make it possible to examine more land surface features, decreasing the need for more expensive data collection methods.

DEPARTMENT OF LABOR

Mine Safety and Health Administration

The Mine Safety and Health Administration uses remote sensing data to help prevent or reduce mine accidents and occupational diseases. Used in conjunction with high- and low-altitude aerial photography and topographic maps, Landsat can detect faults which can cause mine cave-ins. Landsat images provide views of a large area that cannot be duplicated with similar resolution by other means and are very useful in studying regional geography. The Administration has found Landsat images especially useful in detecting faults located in bedded deposits, such as coal mines,but not as useful in hard rock deposits. However, neither Landsat images nor aerial photography alone is capable of providing the entire condition of a geographic area and the Administration must verify this information with onsite observation. With the improvements made to Landsat through the addition of the thematic mapper, the Administration expects to become better at detecting faults.

The Administration is currently trying to update its Landsat images of current mining areas with the use of new products from Landsat 4. The end-product will be linear maps that can be used to design mine roof-control plans or highlight possible fault problems which mining companies can use to help decide where to place future mines.

Most mining areas have already been covered with Landsat imagery, and since geographical features do not change rapidly, future use of satellites will remain constant for the next 5 years. However, a project may be developed to aid the Bureau of Indian Affairs in monitoring mine waste impoundments and waste refuse piles. The project, if implemented, will be used to ensure that nonusable rock excavated from coal mines and deposited into bodies of water (mine waste impoundments) or accumulated into dry piles (refuse piles) do not endanger the safety of the surrounding community or environment.

DEPARTMENT OF TRANSPORTATION

Coast Guard

The Coast Guard uses weather satellites for (1) search and rescue--saving people and property distressed at sea, (2) marine environmental protection--minimizing the damage caused by pollutants, such as oil spills, (3) ice operations--operating the nation's icebreaking vessels for such purposes as facilitating maritime transportation and supporting U.S. polar installations, and (4) the International Ice Patrol--providing an iceberg warning service in the area of the Grand Banks of Newfoundland. It receives imagery and radio signals from the polar orbiting meteorological satellites and uses NOAA and Navy products, such as the Weekly Sea Current Chart, derived from the polar orbiting and geostationary weather satellites. In addition, the Coast Guard is participating in an international demonstration program to investigate using signals relayed from emergency distress radios at sea by the polar orbiting meteorological satellite. The Coast Guard has also used Landsat data in monitoring oil spills.

The Coast Guard expects the use of weather satellites for search and rescue satellite-aided tracking to become fully operational in the future. It also expects to use satellite data to monitor merchant vessel traffic and permit year-round trafficability in Western Arctic waters.

Federal Aviation Administration

The Federal Aviation Administration uses weather satellites in preparing preflight weather briefings to pilots and hazardous weather advisories to help route aircraft around a storm. National Weather Service meteorologists assigned to Federal Aviation Administration air route traffic control centers and Federal Aviation Administration personnel at flight service stations use images from the geostationary weather satellites to prepare the weather advisories and the weather briefings. Data from National Weather Service radar and other Weather Service products, such as maps of surface and upper level winds, are also used. The Federal Aviation Administration considers the satellite pictures to be critical to generating the weather advisories and briefings, believing that program objectives could not be achieved completely without the satellite data.

The Administration expects to continue its use of geostationary data but in the future will receive satellite data directly at its air route traffic control centers, rather than indirectly through the National Weather Service as is done now.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The National Aeronautics and Space Administration (NASA) uses the weather satellites and Landsat in its Earth Science and Applications Research program. NASA integrates the data from these operational systems and other sytems, such as its research and development satellites for its programs. NASA also flies experimental equipment on operational satellites, such as the thematic mapper on Landsat and search and rescue equipment on the most recent polar orbiting weather satellite. NASA works with other federal agencies, state governments, and foreign groups. For example, NASA, NOAA, and the Department of Agriculture have worked jointly on agricultural uses of remote sensing technology. NASA, NOAA, and the Departments of Defense (Air Force) and Transportation (Coast Guard) are working jointly on an international demonstration program for using a satellite system to aid in the search and rescue of aircraft and ships in distress. NASA also has separate agreements for joint participation by Canada and France in the program.

SMITHSONIAN INSTITUTION

The Smithsonian Institution uses weather satellite images to monitor volcanic activity. The Smithsonian created a Scientific Event Alert Network to serve the scientific community by gathering and disseminating information on volcanic activity, earthquakes, and meteorites. Information is gathered from a variety of sources, including scientists, government officials, interested amateurs, and the news media. Satellite images are acquired through interagency cooperation with NOAA. Satellite data add to both the number of eruptions reported and the quality of information about eruptions. For example, satellite data help Indonesia to monitor many dangerous volcanoes in a large, densely populated country with limited transportation and communications by giving a nearly instantaneous overview of explosive volcanoes.

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CHAPTER TEN

MATERIALS PROCESSING IN SPACE*

By Marcia S. Smith
Specialist in Aerospace and Energy Systems

I. INTRODUCTION

Interest in the possibility of processing and manufacturing materials in the near zero gravity environment of space has existed for some time. The first space processing experiments were performed on three Apollo flights (14, 16 and 17), and continued on Skylab, the Apollo-Soyuz Test Project, and a number of sounding rocket launches in the SPAR (Space Processing Applications Rocket) program.

The concept of materials processing in space is based on the fact that in space, such processing can be accomplished without the force of gravity interfering with the procedure. Gravity is ever present on Earth, and its effects can be nullified for only a few seconds using drop towers or "zero-g" aircraft flights. The lack of gravity would allow production of new materials, such as mixtures of metals which can be made in space but not on Earth because the metals have different densities which cause them to settle into layers rather than remaining mixed. Without gravity, droplets of one metal will remain suspended in another of differing density for long periods of time.

Another potentially promising area is crystal growth. On Earth, the growth of homogenous crystals from solutions of melts is hindered by mixing effects caused by convection currents driven by gravity. In the absence of gravity, it has been shown both theoretically and experimentally that crystals can be grown with highly uniform compositions and properties.

NASA's Outlook for Space study concluded in 1976 that space processing and manufacturing were promising areas of endeavor for the future, involving use not only of the space shuttle/Spacelab combination, but of "longer duration stays in some sort of space station facility" as well.[1] NASA's Office of Space Transportation Systems subsequently contracted for two studies of the potential for space industrialization, including space manufacturing, in September 1976.

Both studies were completed in April 1978. The first, by Rockwell International, concerned identification of potential goals for space industrialization and development and assessment of evolutionary program options for realization of those goals, definition of program

*A number of terms are used to describe the production and/or processing of materials in space including materials processing, space processing and space manufacturing. Although there are shades of differences in meaning, the terms are used interchangeably in this chapter.

[1] NASA. Outlook for Space. Washington, NASA, 1976. NASA SP-386. p. 96.

Reproduced from Smith, Marcia S. Materials processing in space. In Congressional Research Service. United States Civilian Space Programs: 1958-1978; report prepared for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives. Volume 1. Washington, For sale by the Supt. of Docs., G.P.O., 1981. p. 807-829.

support demands, evaluation and definition of leading program options, and development of recommendations for program implementation. The second study, performed by Science Applications, Inc., identified future opportunities for space industrialization, quantified their potential benefits, developed and analyzed evolutionary program options required to take advantage of these opportunities, and defined the framework of international governmental, industrial, legal and economic constraints within which space industrialization would evolve. The results of these studies are discussed as appropriate in the sections which follow.

II. CONGRESSIONAL INTEREST

Congress has shown considerable interest in the potential of space manufacturing, both through hearings and the introduction of bills to stimulate private sector involvement in such research.

The Senate Committee on Aeronautical and Space Sciences (which was abolished in 1976 and its functions transferred to the Commerce, Science and Transportation Committee) and the House Science and Technology Committee (formerly Committee on Science and Astronautics) have each held hearings either on space manufacturing specifically, or more generally on the topics of space industrialization or future space programs. Hearings of special note include: Senate—*Space Shuttle Payloads* (Part 2, October 31, 1973), and *Space Processing* (June 17, 1976); House—*Future Space Programs 1975* (July 22, 23, 24, 29, 30, 1975), *Space Industrialization* (September 29, 1977), and *Future Space Programs* (January 24, 25, 26, 1978). All these documents are available from the Government Printing Office.

Legislation has also been introduced bearing on the potential of space manufacturing. Specific legislation to create a Space Industrialization Corporation to provide a funding scheme for meritorious projects has been introduced in the House,[2] and the space policy bills introduced in the Senate [3] include language to promote greater industry involvement in space exploitation, especially space manufacturing.

III. ORGANIZATION WITHIN NASA

In the early part of 1969, NASA established a Materials Sciences and Manufacturing in Space program under the Advanced Missions Program Office of the Office of Manned Space Flight. At the end of the Apollo program, the Office of Manned Space Flight divested itself of all responsibility for payloads to concentrate on development and operation of the space shuttle, and the materials sciences program was therefore transferred to the newly created Office of Applications on April 1, 1973. At this time, its name was changed to the Space Processing Program and placed under the Special Programs Division of the Office of Applications.

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[2] H.R. 2337, introduced on Feb. 22, 1979 by Congressman Don Fuqua, Chairman of the House Committee on Science and Technology.

[3] S. 212, introduced by Senator Harrison Schmitt, ranking minority member of the Senate Commerce, Science and Transportation Subcommittee on Science, Technology and Space on Jan. 24, 1979; S. 244, introduced by Senator Adlai Stevenson III, chairman of that subcommittee, on Jan. 29, 1979.

In January, 1978, the Office of Applications was renamed the Office of Space and Terrestrial Applications and the space processing program was raised to a division level and its title changed once again, this time to the Materials Processing Space Division.

IV. RESULTS FROM PAST EXPERIMENTS

There already have been several experiments concerning materials processing in space both in the United States and abroad. In the United States, experiments were conducted during the Apollo, Skylab and Apollo-Soyuz programs, and using sounding rockets (the SPAR program). The European Space Agency (ESA) has conducted several sounding rocket experiments for space processing and appear very interested in continuing such experiments on the space shuttle. Germany, a member of ESA and largest single contributor to Spacelab, is carrying on a substantial unilateral materials processing in space program. The Soviet Union has conducted a wide variety of space processing experiments, first in 1969 on Soyuz 6 (welding experiments), and again on their manned space station series, Salyut. Recent Russian manned space flights to Salyut 6 have increased their experience with space processing substantially, leading NASA associate administrator for space and terrestrial applications, Anthony Calio, to report to Congress in March 1979 that "The Soviets now have a data base that will not be available in the U.S. program until 1982." [4] The scope of this study, however, does not permit detailed examination of these foreign programs.

A. Apollo 14, 16 and 17

Three U.S. lunar Apollo flights carried early space processing experiments: Apollo 14 (launched January 31, 1971), Apollo 16 (launched April 16, 1972), and Apollo 17 (launched December 7, 1972). The following information on the experiments and their results is taken primarily from the *Apollo Program Summary Report* published by NASA's Johnson Space Center in 1975 (JSC–09423).

1. Composite Casting

Apollo 14 carried composite casting experiments. Composite casting refers to the casting of a material from a mixture of a liquid matrix and solid particles. The Apollo experiments were designed to demonstrate whether or not mixtures of materials having different specific gravities would remain mixed in the liquid state and during freezing in the low gravity environment of a spacecraft. Eighteen samples were provided for the Apollo 14 flight (although only eleven were processed due to time constraints) consisting of fibers, microspheres and gas in an indium-bismuth matrix, or paraffin and sodium-acetate trihydrate.[5]

Sealed metal capsules containing these materials were inserted into an electric furance, heated for a prescribed time and then cooled by placing the capsule onto a heat sink device (some samples were also

[4] Anthony Calio. Prepared Statement to Senate Commerce, Science and Transportation Subcommittee on Science, Technology and Space. Mar. 2, 1979, p. 30.
[5] G. Seibert. Material Sciences in Space. Pt. 1: Review of Space Experiments to Date. ESA Journal, vol. 2, 1978: 8.

shaken to mix the materials). The capsules processed in space were compared with mixtures processed on Earth under otherwise similar conditions. Although a limited range of materials were studied under non-instrumented conditions which were not closely controlled, the demonstrations showed that unique material structures were produced.

2. Heat Flow and Convection

Apollo 14 and Apollo 17 carried three heat flow and convection experiments: a flow pattern experiment to investigate convection caused by surface tension gradients resulting from heating a thin layer of liquid; a radial heating experiment to obtain information on heat flow in a confined gas under low-gravity conditions; and a lineal (or zonal) heating experiment to investigate heat transfer in confined liquids in low gravity.

a. Flow Pattern.—On Apollo 14, the flow pattern cell consisted of a shallow aluminum dish uniformly heated from the bottom to establish a thermal gradient across a thin layer of heavy oil (Krytox) which contained aluminum powder to allow flow patterns to be observed and recorded by a 16 millimeter camera operating at one frame per second. The Apollo 17 experiment was the same except that baffles were added around the periphery of the pan to maintain the liquid level at a uniform depth (in one experiment at 2 millimeters, in another at 4 millimeters).

The Apollo 14 experiment demonstrated conclusively that surface tension alone, without gravity, could generate cellular convection. Apollo 17 confirmed these results, and demonstrated that convection at the 4 millimeter depth showed more regular and larger cells than at the 2 millimeter depth. Convection in 2 millimeter depth solution was less orderly and symmetrical than patterns obtained with ground-based unit, but were more orderly and symmetrical than observed with the Apollo 14 experiment, where a constant depth could not be maintained because of wetting of the cell liner.

b. Radial and Lineal Heating.—The radial heating experiments consisted of a cylindrical dish containing either carbon dioxide gas (Apollo 14) or argon gas (Apollo 17) covered with a glass window coated with a liquid crystal material that changed color when heated. The cell was divided into quadrants with each sector sensitive to different temperature ranges. Changing color patterns, denoting temperature distribution, were recorded by camera.

The lineal heating experiment on Apollo 14 consisted of two glass tubes with cylindrical heating elements surrounding the center of the tubes, with one tube containing distilled water, and the other a 20% sugar solution to produce a fluid with approximately twice the viscosity of pure water. Temperature changes were sensed by liquid crystal strips located along the central axes and walls of the tubes. Color patterns were monitored as heat flowed from the centrally heated region to the ends of the tubes. On Apollo 17, a single glass tube containing Krytox oil was used, and the liquid was heated by a disc heater at one end of the tube rather than a centrally located heater. Temperature changes again were monitored by liquid-crystal strips immersed in the fluid.

In these experiments, scientists expected that conduction and radiation would be the only modes of heat transfer because the driving force for convection would be absent, but the Apollo 14 experimental data showed that temperature changes were occurring faster than could be attributed to conduction and radiation alone. The Apollo 17 results observed no significant convection, and the conclusion was drawn that the Apollo 14 results were caused by motions of the heat flow and convection unit and spacecraft, not by a new, unknown process.

3. Fluid Electrophoresis.—Electrophoresis, a method of separating molecules in a solution by applying an electrical current, is considered a potentially promising area of space processing because of its possible application to separating and purifying valuable biological products, especially isoenzymes.

The electrophoresis experiment on Apollo 14 consisted of an electric system, three electrophoresis cells, and a system to circulate the electrolyte through the cells, all contained in a metal case. Each cell was filled with a different solution: a red and blue dye mixture, hemoglobin, and salmon sperm deoxyribonucleic acid (DNA) in an aqueous solution of boric acid. The red and blue dyes separated as expected, but no action was observed in the hemoglobin or DNA tubes; on return to Earth it was found that the hemoglobin and DNA had been consumed by bacterial action. The resolution of the dye separation was found to be much better in space than on Earth in similar apparatus, and the shape and sharpness of the advancing boundary of separated material was improved in space by the lack of remixing due to convection currents.

Following on the Apollo 14 failures with hemoglobin and DNA, the Apollo 16 experiments used two different particle sizes of polystyrene latex (0.2 and 0.8 micrometer diameter) to simulate the size and density of living cells without the problem of bacterial attack. One cell contained a mixture of the two sizes, one contained only large particles and the third contained only small particles. Electro-osmosis (the movement of liquid with respect to a fixed solid as a result of an applied electric field) occurred resulting in bullet shaped samples. Electro-osmosis had been predicted and the experiment designed to minimize the effect of this occurrence, but its presence, coupled with the formation of large bubbles near the positive electrode, reduced the effectiveness of the demonstration. Data did clearly show the stability of the bands which developed and the sharpness of the particle fronts. The 0.2 and 0.8 micrometer particles combined in one of the cells did not separate into distinct bands as had been expected, but the bands were distorted into the shape of two bullet-shaped surfaces nested together. The leading band in the two cells containing the 0.2/0.8 micrometer mix and only the 0.8 micrometer particles was significantly more pointed than in the cell containing only 0.2 micrometer particles.

B. Skylab

The U.S. space station Skylab hosted three three-man crews from 1973 to 1974 that performed twenty-one materials processing experiments, shown in Table 10-1 (there were fourteen experiments, seven

of which were performed twice). Three experiments were performed by the Skylab 2 crew (the first manned mission) in the Materials Processing Facility (designated M 512), while a fourth experiment had to be omitted at the last minute to make room for repair equipment for the workshop (which had been damaged during launch, see Chapter Six). This experiment would have investigated gallium arsenide crystal growth.

TABLE 10–1

SKYLAB MATERIALS PROCESSING EXPERIMENTS *

EXPERIMENTS	SKYLAB MISSION II	III	IV
MATERIALS PROCESSING FACILITY			
M551: Metals-Melting Experiment	X		
M552: Exothermic Brazing Experiment	X		
M553: Sphere-Forming Experiment	X		
MULTIPURPOSE FURNACE SYSTEM			
M556: Vapor Growth of II-VI Compounds		X	X
M557: Immiscible Alloy Compositions		X	X
M558: Radioactive-Tracer Diffusion		X	
M559: Microsegregation in Germanium		X	
M560: Growth of Spherical Crystals		X	X
M561: Whisker-Reinforced Composites		X	X
M562: Indium-Antimonide Crystals		X	X
M563: Mixed III-V Crystal Growth		X	X
M564: Alkali Halide Eutectics		X	
M565: Silver Grids Melted in Space		X	
M566: Copper-Aluminum Eutectic		X	X

* Source: James H. Bredt and Brian O. Montgomery. New Challenges for Industry. Astronautics and Aeronautics, May 1975: 24.

The remaining eleven experiments were performed in the Multipurpose Furnace System (M 518), with all eleven performed once by the Skylab 3 crew and seven repeated by Skylab 4. (Originally, the Skylab 3 crew was not scheduled to perform any materials processing experiments, but they had enough available time that they were allowed to go ahead with the Multipurpose Furnace Experiments.)[6]

Results from the Skylab experiments have been published in *Proceedings, Third Space Processing Symposium: Skylab Results* (Volumes 1 and 2, NASA, Marshall Space Flight Center, June 1974 M–74–5), which served as the primary source for information in this section.

1. M 512 and M 518 Processing Facilities

The M 512 processing facility was located in the Multiple Docking Adapter and was comprised of a work chamber, a control panel, an electron beam gun, and storage boxes for experiment modules and an-

[6] Michael L. Yaffee. Skylab Science Data Found Promising. Aviation Week and Space Technology, Feb. 18, 1974 : 56.

cillary equipment. It was mounted on a honeycomb panel which also served as a heat radiator.

The work chamber could be vented to space, thereby providing an evacuated chamber when required. The chamber was illuminated and had windows so the experiments could be observed while in process by the crew and photographed by a fixed motion picture camera. The work chamber included a mount which accommodated each experiment in turn and doubled as a heat sink with a predetermined and calibrated thermal impedance. An electric connector was located near the mount for power and signals for all experiments except those using the M 518 furnace.

The electron beam gun, with an output of 2 kilowatts, was used to melt specimens in the Metals Melting and Sphere Forming experiments. The gun was powered by batteries so was independent of Skylab's power system.

The M 518 Multipurpose Furnace was installed in the M 512 chember when in use. It could produce temperatures as high as 1000°C, could hold the temperature constant for preset lengths of time for specific experiments, and cool at constant programmed rates, resulting in a predictable but not constant rate of solidification of the molten samples. It required 200 watts of power which were drawn from the spacecraft power supply.

2. Experiments With the M 512 Material Processing Facility

a. M 551: Metal Melting Experiment.—This experiment used the electron beam gun for cut-through, full and partial penetration melts of aluminum, stainless steel and tantalum to study the effects that occur during welding in space. Welding in space may be important if large space structures are to be constructed in the future. The experiment proved that such welding is feasible, and found that the welds made in space contained small, equiaxed grains compared with large, elongated grains in samples processed under otherwise similar conditions on Earth.

b. M 552: Exothermic Brazing.—This experiment investigated the potential of brazing as a method of joining tubes for assembly, repair and maintenance in space, and to study the spreading, mixing and capillary action of molten braze material in near zero gravity. Four specimens were processed, each consisting of a tube, sleeve, inserts (spacers) and silver-copper-lithium braze rings. Two of the samples contained pure nickel tubes and sleeves, while the other were type 304 L stainless steel. A radioactive isotope (110-Silver) was added to one of the nickel specimens to assist in analysis of capillary flow. The experiment was very successful, producing excellent braze joints with less porosity and finer microstructure than could be achieved on Earth.

c. M 553: Sphere Forming Experiment.—To study the effects of weightlessness on containerless solidification processes, twenty samples of pure nickel and three nickel alloys (containing copper, tin, or silver) were mounted on a disk which revolved in front of the electron beam gun. The materials melted and then resolidified one by one. Some separated from the disk and resolidified while free floating in the chamber. The solidified samples provided a detailed record of the freezing process, and two of the nickel alloy samples formed large internal

voids by an as yet unexplained spontaneous vaporization process during the initial stages of cooling.

3. Experiments Using the M 518 Multipurpose Furnace System

a. M 556: Crystal Growth by Vapor Transport.—Experiment M 556 was designed to study the quality of crystals grown by chemical vapor transport in the near zero gravity environment of Skylab compared with Earth-grown crystals. Six transport experiments employing different concentrations of transport agent (germanium tetraiodide) and two temperature gradients were performed on germanium selenide and germanium telluride crystals which are compound semiconductors. The experiments showed that there is considerable improvement with the space processed crystals in terms of surface perfection, crystalline homogeneity and defect density. Scientists also observed greater mass transport rates than had been expected (in measuring the amount of crystal material deposited from the vapor in a given time at different pressures, the space experiment deposited up to ten times as much material as had been predicted) indicating that existing transport models are incomplete. The experiment showed that larger and more perfect crystals could be grown in space (in the case of germanium selenide, one crystal grew six times larger than expected).

b. M 557: Immiscible Alloy Composition.—This experiment was designed to study the effects of near zero gravity on the processing of immiscible materials. Three cartridges, each containing three separate experiment ampoules, were processed simultaneously and compared with similar specimens processed in one-g. The first two cartridges (containing ampoules of gold-germanium, and lead-zinc-antimony) were processed in the isothermal section of the furnace while the third (lead-tin-indium) was processed in the gradient region. In all of the cases, the space processed specimens showed better homogenization and microstructural appearances than in prior Earth-based experiments. The electronic behavior of the space processed specimens was comparable to that of the one-g samples, however.

c. M 558: Radioactive Tracer Diffusion.—Experiment M 558 was designed to detect any disturbances of pure diffusion behavior that might be caused by spacecraft motion. Radioactive atoms of zinc–65 were allowed to diffuse through rods of zinc metal melted in the Multipurpose Furnace. Ground processed samples are mixed by convection, so that the radioactive zinc is evenly distributed through the sample. In the space experiment, the distribution accurately reproduced mathematical predictions based on the theory of pure diffusion.

d. M 559: Influence of Gravity-Free Solidification on Microsegregation.—Three germanium crystals, doped with gallium, antimony or boron, were melted and directionally resolidified using the Multipurpose Furnace. Results from the gallium-doped germanium crystal showed that microsegregation in space is reduced by two to five-fold in the bulk and eight-fold near the surface, while macrosegregation is reduced six-fold in the bulk. Improved homogeneity can be exploited to produce solid state electronic devices with more predictable and uniform performance.

e. M 560: Seeded, Containerless Solidification of Indium Antimonide.—Indium antimonide crystals were contained in a cylinder such

that one end was held in a closely fitting container and the other extended into an enlarged cavity. The cavity was heated while the other end of the cylinder remained cool. A drop of molten material formed on the end of each sample in its cavity and was retained by surface tension and adhesion. The sample was then solidified directionally by lowering the cavity temperature and letting heat leak away through the remaining solid part of the crystal. It had been expected that the crystals would retain the shape of the molten drops from which they solidified, but they did not. The reasons are not well understood, but it could only have occurred if the diameter of the molten drop remained larger than the diameter of the solid. In addition, approximately 30% of the surface consisted of flat facets oriented in planes defined by the underlying crystal structure, and the number of imperfections in the crystals decreased steadily as growth proceeded.

The experiment demonstrated that "forces intrinsic to the solidification process itself determine the shape of a single crystal solidified from a melt under zero-g. Moreover, these forces apparently favor the formation of crystals with flat facets and few imperfections—both very desirable characteristics in crystals for electronics, because most solid-state devices employ flat wafers and suffer degradation in performance from crystal imperfections." [7]

f. M561: Preparation of Silicon Carbide Whisker Reinforced Silver Composite Material in Weightless Environment.—This Japanese experiment was designed to produce void free matrices of silver, reinforced with oriented whiskers of silicon carbide. The results indicated the influences of buoyancy and thermal convection in the samples processed on the ground versus those processed in space where those forces do not exist. The space grown crystals showed a uniform distribution of hardness values and did not have any floating whiskers, although voids were not completely eliminated from the samples because the springs provided to keep them under pressure weakened when the samples were heated.

g. M 562: Steady State Growth and Segregation Under Zero Gravity: Indium Antimonide.—Similar to experiment M 559, M 562 used three indium antimonide crystals (one intrinsic, one doped with tin, and the third doped with tellurium) to study steady state diffusion during crystal growth in near zero gravity. Approximately half of each sample was melted and then resolidified directionally, beginning from the interface between the melt and the original crystal. The region near the initial regrowth interface revealed no dopant inhomogeneties across the entire diameter of the crystal, showing the advantage of performing such processes in space. The experiment identified the origin of segregation discontinuities associated with facet growth, the mode of nucleation and propagation of rotational twin boundaries, and the specific effect of mechanical-shock perturbations on segregation.

h. M 563: Directional Solidification of Indium Antimonide and Gallium Antimonide Alloys.—This experiment was designed to study how weightlessness affects directional solidification of binary semiconductor alloys, and to grow mixed crystals of indium antimonide

[7] James H. Bredt and Brian O. Montgomery. New Challenges for Industry. Astronautics and Aeronautics, May 1975 : 28.

and gallium antimonide from a convectionless melt to improve perfection. By varying the proportions in such alloys, their semiconductor properties can be adjusted to values optimized for various application. In this experiment, however, conditions for the growth of single crystals were not achieved and the materials consequently did not solidify as homogenous alloys.

i. M 564: Halide Eutectic Growth.—Experiment M 564 was designed to produce oriented rod structures of sodium fluoride in a sodium chloride-sodium fluoride eutectic. The end product was expected to have fiber-optic properties useful for infrared image transmission if continuous fibers could be produced. Continuous fibers were produced in the space based samples (compared to discontinuous fibers in the Earth-processed samples), and this was attributed to the absence of convection currents in the liquid during solidification.

j. M. 565: Silver Samples Melted in Space.—This Belgian experiment was designed to study the behavior of porous material when melted and resolidified in near zero gravity. Very fine porous structures are desired for filtration and absorption. Two types of samples were used: perforated discs and a fibre compact. Most of the original porosity disappeared during the melting stage, which scientists believe could be avoided by using different heating and pressure conditions or using samples with closed pores in future experiments.

k. M 566: Copper-Aluminum Eutectic.—Portions of three copper-aluminum specimens were melted and resolidified, resulting in data which showed that the aligned eutectic in space grown specimens had fewer defects: an improvement of 12% in average defect spacing and a decrease in 20% in the average fault density.

C. Apollo-Soyuz Test Project

Although the focus of the 1975 Apollo-Soyuz Test Project was to demonstrate the possibility of linking two spaceships from different nations in space (the U.S. Apollo with the Russian Soyuz, see Chapter Six), the mission also carried a variety of scientific experiments. Two biological materials processing experiments were conducted, along with seven U.S. solid materials processing experiments. Summaries of the ASTP experiments and their results have been published in detail in *Apollo-Soyuz Test Project: Summary Science Report* (NASA SP–412, 1977) from which the following information is summarized.

1. Biological Materials Processing (Electrophoresis)

Two electrophoresis experiments were conducted on ASTP, the first (Electrophoresis Technology Experiment) was American, while the second (Electrophoresis Experiment) was German.

The U.S. experiment was based on previous experiments conducted on Apollo 14 and 16 and designed to demonstrate the static column (zonal) method of electrophoresis. A closed tube filled with buffer solution was used with an electric field aligned along the tube into which the sample was introduced as a frozen pellet near one end. After a period of time to allow the sample pellet to melt, the electric field was turned on and the sample was transported along the tube to separate its faster and slower moving components. At the end of the separation run, the solution in the entire tube was frozen to immobilize the

sample fractions and returned to Earth for analysis. Five different mixtures were processed: mixture of rabbit, human and horse fixed red blood cells; human peripheral blood lymphocytes; human fetal kidney cells; fixed rabbit and human red blood cells; and fresh rabbit and human red blood cells. The last two were processed by isotachophoresis, a variant of electrophoresis in which different buffer solutions are used ahead of and behind the sample in the tube.

The experiment was designed to demonstrate requirements for application of electrophoresis on future space flights: preservation of cell viability before processing; processing; and preservation of viability after processing.

Zonal electrophoresis was accomplished by separating the fixed red blood cells species from their mixture, although the lympocytes did not electrophorese successfully (possibly because the cells lost viability due to pH fluctuations). The isotachophoresis experiments were only partially successful because only frontal boundaries developed. The kidney cell separation experiments, which were important to scientists interested in increasing supplies of urokinase [8] were successful.

The German experiment was designed to demonstrate the free-flow method of electrophoresis in a near zero gravity environment. In this procedure, the buffer solution flows continuously through a rectangular duct and the cell mixture is continuously inserted into the flow. Rather than being aligned in the same direction of the flow, in this method the electric field is perpendicular to flow so that the cells separate laterally as they pass downstream. Four mixtures were processed: rat bone marrow cells; fixed rabbit and human red blood cells; rat spleen cells; and rat lymph node cells with human red blood cells as markers. Separated streams were detected by a photo-optical system and data stored on magnetic tape.

The photo-optical detection system developed an anomaly during flight, so that the ultraviolet lamps in the detector system were 42 percent brighter than they were supposed to be, resulting in reduced data. Despite this development, results from the German experiments showed that electrophoresis was accomplished with a tenfold increase in the throughput rate and with at least as sharp cell separation as is achievable on Earth.

2. Solid Materials Processing Experiments

Six U.S. high temperature and one low temperature solid materials processing experiments were performed on ASTP. The six high temperature experiments involved the use of a Multipurpose Electric Furnace, an advanced version of the furnace used on the Skylab workshop. Improvements included capability of providing higher temperatures (nominally 1423°K) with no increase in the power requirement, and the ability to allow controlled, variable rate cooldown, including addition of a helium injection rapid cooldown system which reduced the time needed to cool the samples from 20 hours to three. Each experiment involved a set of three stainless steel cartridges, with each cartridge containing from one to three samples. All three cartridges were processed at the same time.

a. Surface Tension Induced Convection.—This experiment was designed to detect possible convection due to surface tension gradients

[8] Urokinase is an enzyme which can dissolve blood clots.

resulting from compositional gradients in a sample of pure lead interfaced to an alloy of lead and 0.05 atomic percent gold. Two diffusion temperatures were used (923°K and 723°K), and results showed that incomplete mixing occurred in a pattern not explainable by diffusion. Possible causes for this include small amounts of convection induced by spacecraft motion, fluid motions caused by the density change of lead during freezing, or segregation effects due to gold's differing solubilities in liquid and solid lead.

b. Monotectic and Syntectic Alloys.—In this experiment two materials (aluminum antimonide and lead-zinc) were melted and solidified to observe the effects of these processes in near-zero gravity. Aluminum antimonide has potential application as a solar cell material, but difficulties have been encountered in producing the material on Earth because of difficulty in achieving chemical homogeneity and because the material is highly reactive with moisture. The latter was thought to be the result of secondary phases which occur in Earth-processing, and data from the space processing experiments showed considerably less of the undesirable secondary phase. Major improvements in macroscopic and microscopic homogeneity were also achieved.

The lead-zinc experiment was designed to show phase segregation effects in near-zero gravity conditions. The two elements are immiscible in the liquid state and separate rapidly upon melting because of their large density differences. It was expected that they could be successfully kept mixed in space. The experiment produced unexpected results however. The materials separated into two macroscopic regions—one zinc, and one lead with a zinc bubble in it. No difficulties were encountered in processing the materials, with requisite temperatures achieved as scheduled, leading scientists to conclude that the temperature needed for the alloying to occur must be higher than what had been previously thought.

c. Interface Marking in Crystals.—The third high temperature solid materials processing experiment was designed to explore crystal growth and impurity segregation characteristics in a directionally solidifying material. Gallium-doped germanium single crystals were partially melted and then regrown while current pulses were transmitted across the travelling solid/melt interface at four second intervals to provide identifiable marks enabling determination of growth rates. The rate of crystal growth was the same for the space processed sample as for those processed under similar temperature conditions on Earth. The segregation results showed that the dopant concentration increased as the interface travelled over approximately 1.5 centimeters, but with continuing growth, the dopant concentration decreased, rather than achieving a steady-state value. The Principal Investigator for the experiments concluded that this unexpected behavior was a result of the geometry of the growth system, rather than a result of the near zero gravity environment.

d. Zero-G Processing of Magnets.—The fourth experiment involved investigation of the potential for enhancing magnetic coercive strength of two materials: an alloy of manganese and bismuth, and an alloy of copper, cobalt and cerium. The manganese-bismuth alloy contained very fine needles of the magnetic compound MnBi in a bismuth metal matrix and achieved significantly improved coercive strength at low

temperatures. The cobalt-cerium alloy reacted with its containing crucible, so experimental results were inconclusive.

e. Crystal Growth from Vapor Phase.—Following on the Skylab experiments with crystal growth from the vapor phase involving germanium selenide and germanium telluride using germanium tetraiodide as a transport agent, this ASTP experiment extended the investigations to new materials. Three experiments were performed using three chemical compounds, two transport agents, and one inert gas. Results showed improvement of the space grown crystals over Earth-grown crystals in terms of chemical and crystalline homogeneity, surface morphology, and bulk perfection. Measurements of the rate of crystal growth confirmed results of the Skylab experiments.

f. Halide Eutectic Growth.—Another follow-on to Skylab investigations, this experiment was designed to grow continuous fibers of lithium floride in a matrix of sodium chloride to demonstrate the advantages of space processing for producing infrared-transmitting fiber optics. The experiment was successful, producing lithium fluoride crystals with improved transmittance over a wider wavelength range with better image quality than had been obtained on Earth.

g. Crystal Growth.—This was the one low temperature experiment (it did not involve use of the multipurpose furnace), and was designed to demonstrate the growth of crystals by diffusion of appropriate reactant toward each other through pure water at ambient spacecraft cabin temperature. On Earth, the most successful growth process based on this principle involves using a gel to support the growing crystals and suppress convection. This method results in reduced diffusion rates and multiple nucleation of crystals in the gel, which usually prevents the growth of large single crystals. Without the force of gravity, it was reasoned that the gel would not be required to support the growing crystals, so pure water was used instead. Three crystals were grown: calcium tartrate, calcium carbonate, and lead sulfide. The crystals obtained were of a size and quality comparable to the best grown on Earth in the same length of time; the best results were obtained with calcium tartrate and the least successful with lead sulfide.

D. Space Processing Applications Rockets (SPAR)

The SPAR program began in 1975 and through the end of 1978 had launched a total of five Black Brant VC sounding rockets from the White Sands Missile Range in New Mexico. Each flight provides approximately five minutes of weightlessness (see Chapter Five for a discussion of sounding rockets). Four more SPAR flights are planned, two in 1979 and two in 1980. SPAR flights are designed to provide basic information about materials processing during the hiatus in U.S. manned space flight.

SPAR I, launched on December 11, 1975, carried nine experiments, all of which functioned correctly, entitled: space solidification of Pb-Sb (lead antimonide) eutectic; feasibility of producing closed-cell metal foams in a zero-gravity environment from sputter-deposited insert gas-bearing metals and alloys; uniform dispersions of crystallization processing; liquid mixing; direct observation of solidification

as a function of gravity levels; casting dispersion-strengthened composites at zero gravity; thermal migration of bubbles and their interaction with modification interfaces; contained polycrystalline solidification in low gravity; and preparation of a special alloy under zero gravity for magnetic hard superconductors.

The six experiments on SPAR II, launched May 17, 1976, also worked correctly. Three of the experiments were repeats from SPAR I (space solification of lead antimonide eutectic; feasibility of producing closed cell metal foams in a zero gravity environment from sputter deposited inert gas-bearing metals and alloys; casting dispersion strengthened composites at zero gravity) and there were three new experiments (direct observation of dendrite remelting and macrosegregation in casting; agglomeration in immisible liquids; and solidification behavior on aluminum-indium alloys under zero gravity conditions.)

On December 14, 1976, SPAR III was launched and continued the success of the series with all five experiments functioning properly: liquid mixing; interaction of bubbles with solidification interfaces; epitaxial growth of single crystal film; containerless processing of beryllium; and contact and coalescence of viscous bodies.

In 1977, the SPAR program encountered its first failure. At the beginning of the program it had been decided to launch SPAR missions at the rate of two to three per year. Although all experiments on the first three flights functioned correctly, by the time of the fourth launch on June 21, 1977, problems developed and none of the four experiments worked. (The four experiments carried on SPAR IV which did not function were: Uniform Dispersion by Crystallization Processing, Contained Polycrystalline Solidification in Low-g, Containerless Processing of Amorphous Ferromagnetic Materials, and Containerless Processing Technology.) NASA associate administrator for space and terrestrial applications, Anthony Calio, reported to Congress in September 1978 that these anomalies were the result of experiment and equipment developers taking technical risks because they were constrained to flight dates selected in the early stages of their work.[9] As a result, the fifth SPAR flight, originally scheduled for launch in the fall of 1977, was postponed for almost a year so that no experiment would be flown until its technical and scientific readiness had been verified.

SPAR V was flown on September 11, 1978 carrying four experiments, all of which functioned correctly. SPAR V carried the following experiments (two of which were repeated from SPAR IV): Uniform Dispersion by Crystallization Processing, Dendrite Remelting and Macrosegregation, Agglomeration in Immiscible Liquids, and Contained Polycrystalline Solidification in Low-g.

V. FUTURE PROGRAMS

SPAR flights are expected to continue through 1980, after which a Materials Experiment Assembly (MEA) will be used on early shuttle

[9] Dr. Anthony Calio. U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. 1980 NASA Authorization (Program Review). Hearings. 95th Congress, 2d session, Sept. 25, 26, 27, 1978. Washington, U.S. Government Printing Office, 1978. p. 176.

flights to perform similar experiments. MEA is a self contained experimental package with its own power source and heat rejection capability so that only simple interfaces with the shuttle will be necessary. SPAR payload apparatus will be installed in the MEA to perform the experiments. NASA has identified several areas for early materials processing studies, as shown in Table 10–2.

Rockwell International performed a study under contract to NASA's Office of Space Transportation Systems from September 1976 through April 1978 to identify potential goals for space industrialization in general, including the development and assessment of evolutionary program options for realizing those goals and definition of program support demands, evaluation and definition of leading program options, and development of recommendations for program implementation.[10]

The report concluded that there are a number of attractive opportunities in the area of manufacturing products in space, shown in Table 10–3. To accomplish the goals set forth in the report, Rockwell proposes that the space shuttle be used to continue experiments which will prove basic space processing concepts, followed by free-flying Space Processing Facilities (SPF). Each SPF would consist of a solar cell power array and a modified external tank from the shuttle (see Chapter Seven) left in orbit by an earlier shuttle mission. The SPF itself would be automated, but would require servicing by the shuttle.

Weighing 68,000 kilograms, the SPF would have a continuous power level of 300 kilowatts available from nickel-hydrogen batteries (charged by solar cell array.) The space shuttle would make regular visits to the SPF, providing raw materials for the manufacturing operations and retrieving materials already processed. The facility would be used primarily for zone refining and crystal growth, and would have fiifteen furnaces producing 750 boules of finished product every sixty days, or 4,500 boules per year weighing 21,150 kilograms. Rockwell suggests deployment of ten SPF's, requiring thirty shuttle flights per year for servicing.[11]

Ultimately, if materials processing in space proves economically viable, longer duration manned or unmanned facilities could be constructed. One such concept now being discussed is a Space Manufacturing Facility involving permanent manned space habitats for a variety of uses, including space manufacturing. Dr. Gerard O'Neill of Princeton University has been a leading advocate of such facilities placed at one of the Lagrange coordinates where the gravitational forces of the Earth and Moon balance each other out. He has specifically recommended that such a space manufacturing facility be used to manufacture satellite power stations for placement in geosynchronous Earth orbit for electric power production and transmission in Earth (see Chapter Fifteen).

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[10] Rockwell International. Space Division. Space Industrialization. [n.p.]. Apr. 14, 1978. Vols. 1–4. SD 78–AP–0055–1, SD 78–AP–0055–2, SD 78–AP–0055–3, AD 78–AP–0055–4. NASA Contract-32198.

[11] Ibid., Executive Summary (vol. 1), pp. 32–33.

TABLE 10-2

NASA CANDIDATE AREAS FOR EARLY MATERIALS PROCESSING IN SPACE EXPERIMENTS *

AREA OF RESEARCH	TASK	APPLICATION
Infrared Detector Materials	Study problems associated with compositional control required to satisfy advanced remote sensing needs.	Infrared imaging systems for military surveillance, earth sensing applications, law enforcement, scientific instrumentation, medical diagnosis.
Inertial Confinement Fusion Targets	Study problems associated with geometrical control to produce more efficient implosion conditions in large size, hydrogen filled glass shells.	Short range applications in fusion research for weapons and power generation programs. Long range possibilities for energy production.
Containerless Processing	Development of fundamental physical understanding of positionirg force fields and the utility for new materials processing.	Scientific studies of reactive materials, development of glass shell production methods, control of purity in glasses.
Floating Zone Experiments	Study melt surface and flows related to surface tension gradients in the floating zone configuration.	Separate and quantify fluid flow effects in earth-based floating zone processes as well as study new configurations for space experiments.
Heat Pipe Technology	Development of high temperature heat pipes to provide advanced control capabilities of the thermal environment of materials processing in space.	Establish controlled isothermal and very high temperature-gradient capabilities to grow solid-solution semiconductor crystals from the melt under stabilizing conditions.
Space Vacuum Research	Identification of extra high vacuum characteristics associated with orbiting molecular wake shield environment.	Extend range of important experimental parameters to perform vacuum science experiments and also to identify utility of this new environment for materials processing.
Bioprocessing Studies	Study of heat and mass transport problems limiting separation and synthesis of biomaterials in earth-based technologies.	Improve efficiency of ground-based bioprocessing methods and identify candidate techniques which take unique advantage of weightless conditions.

* Dr. Anthony Calio. In U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. 1980 NASA Authorization (Program Review). Hearings. 95th Congress, 2nd session, September 25, 26, 27, 1978. Washington, U.S. Govt. Print. Off., 1978. pp. 174, 176.

TABLE 10-8

ROCKWELL INTERNATIONAL LIST OF ATTRACTIVE OPPORTUNITIES IN PRODUCTS AREA OF SPACE MANUFACTURING *

ORGANIC

* Isozymes
* Genetic engineering of hybrid plants
* Urokinase
* Insulin
* New antibiotics via rapid mutation

INORGANIC

* Large crystals
* Super large-scale integrated circuits
* Transparent oxide materials
* Surface acoustic wave devices
* New glasses (including fiber optics)
* Tungsten X-ray target material
* Hollow ball bearings
* High-temperature turbine blades
* Separation of radioisotopes
* High strength permanent magnets
* Magnetic bubble memory crystal film
* Thin film electronic devices
* Filaments for high-intensity lamps
* Aluminum-lead lubricated alloys
* Continuous ribbon crystal growth
* Cutting tools
* Fusion targets
* Microspheres

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* Rockwell International. Space Division. Space Industrialization. Vol. 1. Executive Summary. [n.p., April 14, 1978], p. 10.

VI. VIABILITY OF PROGRAM

The question of whether a materials processing in space program is viable depends on a variety of factors, including whether industry will be interested in the processes or materials so produced, and whether such materials will be economic for use by the general public.

A. INDUSTRY INTEREST

The ultimate commercial viability of materials processing in space may depend on whether industry is interested either in the processes themselves or the materials manufactured in space. To date, little re-

search appears to have been done to determine just exactly what industrial interest in this area might be, in the United States or abroad.

One survey was conducted by Arthur M. Dula, a patent attorney, and Ann Roebke, an industrial anthropologist in 1977 which surveyed 378 companies selected from the Fortune 500 list of American industries and the Fortune 300 list of American service industries. Twenty percent of the companies responded, while another seven percent stated either that their company had no connection with the space program or had a policy against responding to questionnaires. The survey showed that although 30% of those responding were aware of and interested in communications satellites (see Volume II) and satellite power stations (see Chapter Fifteen), less than a tenth of them were interested in materials processing in space such as pharmaceuticals, ultra-pure chemicals or crystal growth.[12]

Dula and Roebke found that a large majority of respondents did not consider tax treatment of space investment expenses and manufacturing profit important in determining whether their company would participate in space industrialization, although the issue of patent rights was considered extremely important. The survey results showed that a large majority of the respondents would either not consider or adversely consider space research if the Government retained patent rights and granted the company only royalty free licenses. Conversely, the respondents indicated that if the Government waived claims to patent rights on space-related discoveries, they would be encouraged towards participating in space industrialization.

Science Applications Inc. (SAI) performed a study under contract to NASA from September 1976 through April 1978 to identify future opportunities for space industrialization, quantify their potential benefits, develop and analyze evolutionary program options required to take advantage of these opportunities, and to define the framework of international governmental, industrial, legal and economic constraints within which space industrialization must evolve.

In considering the economic feasibility of space manufacturing, SAI contacted nine non-aerospace product manufacturers who, according to SAI, had little or no previous contact with space processing or manufacturing concepts: Arthur D. Little, Inc.; Ball Brothers Research Corporation; Shell Oil Company; Talley Industries, Inc.; U.S. Polymeric Corporation; Arvin Industries, Inc.; Olin Chemicals Corporation; Union Carbide Corporation; and a ninth contact who was an individual investor and past company president. Each company was provided with general information about space processing and manufacturing and the study SAI was performing for NASA, and then queried about their perspective of the market for space products.[13]

Survey results showed that the "domestic industrial world is not aware of the real import of the NASA Space Shuttle or of NASA activities in Space Industrialization." Specific comments from the in-

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[12] Arthur M. Dula. How Do U.S. Companies View Space Industrialization? Astronautics and Aeronautics. vol. 15. April 1977: 44–46.

[13] Science Applications Inc. Space Industrialization. Huntsville, Ala., Apr. 15. 1978. Volumes 1–4. SAI–79–602–HU. SAI–79–603–HU. SAI–79–604–HU. and SAI–79–605–HU. NASA Contract NAS8–32197. The information for this section is taken from Volume 3—Space Industrialization: World and Domestic Implications. pp. 70–75.

dustrial companies included: "The products are poorly defined at this time"; "The markets are too indefinite yet"; "The risks are very large relative to the capital outlay required"; and "The return on investment period is too long."

Despite these rather negative views, the respondents state that they thought their companies would become involved in space industrialization if their competitors did. They also commented that the prospects for space industrialization were "interesting," and that an appropriate risk-reducing or risk-sharing policy on the part of the Federal Government would stimulate private industrial interest. Better communication between NASA and themselves was cited as an area where work was needed, and the respondents felt that it was NASA's responsibility to establish improved communication since it had the service to sell to them.

SAI concluded that to generate industry interest in space manufacturing, NASA should: (1) establish better communications with domestic industry by means of an interface organization, a space industrialization newsletter with background and current information, and continual feedback from domestic industry; (2) establish a means of sharing costs and risks of space industrialization research and development; (3) reduce space transportation cost; and (4) make space industrialization research relevant to potential products.[14]

In 1977, the President of Battelle Memorial Institute, Dr. Sherwood Fawcett, suggested one method for establishing more government/industry cooperation in the field of materials processing in space. Emphasizing that before industry can invest stockholder's money in a new product or procedure, firm Government policies on costs, liability and proprietary rights are needed. Dr. Fawcett suggested establishment of a Space Industrialization Trust Fund by the Federal Government.[15]

As proposed by Dr. Fawcett, the Trust Fund would sponsor research and development programs to be performed by or for a U.S. company. The company would certify that a project would lead to a new product or process which would utilize the space environment, have a potential of generating new income and public benefits through its utilization, and whose results would be used by the company if the work was successful. All information and intellectual property generated would be protected and licensed by the Government with payment of royalities to the Trust Fund up to the cost of the project plus interest. This money would then go to finance other projects. According to Fawcett, the Trust Fund concept would provide "an enormous incentive and stimulant to private industry. The public is benefited because the 'winners' pay back with interest and the 'losers' provide information which enable a future winner to be made."[16]

NASA has established a Commercial Space Processing Development Office at Marshall Space Flight Center to study legal, institutional and economic issues involved in private sector space processing activities.

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[14] Ibid., p. 75.
[15] Dr. Sherwood Fawcett. In U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space and Applications. Space Industrialization. Hearings. 95th Congress, 1st session, Sept. 29, 1977. Washington, U.S. Government Printing Office, 1977. p. 139.
[16] Ibid.

B. Economic Viability

Assuming that industry does exhibit an interest in material processing in space, the question of whether products so produced will be economically viable on Earth will still remain an issue. It has been reported [17] that NASA, Dow Chemical Company and Polysciences Inc. have reached an agreement on marketing latex spheres produced on the first materials processing shuttle flight in the early 1980's (these spheres are now used primarily for calibrating electron microscopes, although larger sizes which can be made in space could be used in sizing blood particles and aiding the treatment of certain lesions of the eye). The companies would reimburse NASA for the manufacturing services and market the spheres themselves to determine how such products might fare in actual market demonstration.

The National Academy of Sciences' report on the scientific and technological aspects of materials processing in space (discussed in the next section) states that the study group did not discover "any examples of economically justifiable processes for producing materials in space and [the Committee] recommends that this area of material technology not be emphasized in NASA's program." [18]

By contrast, the study discussed in the previous section by Science Applications, Inc. (SAI) showed a large market for some space produced materials. SAI noted, however, that "It is important to realize that these analyses were made in order to get some data on what the future potential might be. As this implies, the expected answer was anticipated to be nothing more than a "ballpark" number. Thus no claims are made relative to the viability of any specific products called out here . . . With a sufficient reduction in launch costs to Low Earth Orbit (LEO), say $5 to $50 per pound, it is quite probable that these market projections will (in the aggregate) prove much too conservative." [19]

In testimony before the House Science and Technology Committee in January 1978, G. Harry Stine, a member of the study team, revealed some of the study's conclusions.[20] While cautioning that there were many unknown variables which might change the forecasts included in the report, Mr. Stine reported that, for example, the potential market for space-produced perishable cutting tools in the year 2000 was estimated to range from $280 million to $2.8 billion. For space-produced bearing materials, he reported an estimated market of from $69 million to $690 million in the year 2000.

These attempts to quantify commercial prospects, and therefore economic viability, for materials processing in space must be considered speculative in nature since there are so many unknowns, especially economically, for the United States between now and the year 2000.

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[17] Craig Covault. Materials Processing in Space Planned. Aviation Week and Space Technology, Oct. 31, 1977: 52–53. NASA claims that interest has been expressed, but no agreement reached. (Private communication, May 3, 1979).

[18] U.S. National Academy of Sciences. National Research Council. Space Applications Board. Materials Processing in Space. Washington, National Academy of Sciences, 1978. p. 5.

[19] Science Applications, Inc. Space Industrialization (Vol. 2)—Opportunities, Markets and Programs. Huntsville, Ala., Apr. 15, 1978. SAI–79–603–HU. p. 227.

[20] U.S. Congress. House. Committee on Science and Technology. Future Space Programs. Hearings, 95th Congress, 2d session, Jan. 24, 25, 26, 1978. Washington, U.S. Government Printing Office, 1978. pp. 3–54.

C. National Academy of Sciences Report

In the fall of 1978, the National Academy of Sciences' Space Applications Board released a study entitled "Materials Processing in Space," prepared under contract to NASA, which investigated materials processing in space from a science and technology viewpoint.[21]

1. Need for Preflight Investigations

The study emphasized that space based procedures must rely on data from previously conducted Earth-based experiments, and that without strong basic knowledge of the behavior of materials on the surface of the planet, little new will be learned in space. The question of whether NASA has provided adequate support for preflight investigations had been raised previously by space processing researchers.[22]

While criticizing the early NASA space processing program for poorly conceived and designed experiments from which weak conclusions were drawn and, in some cases, over-publicized, the report stated that "there is opportunity for meaningful science and technology developed from experiment in space *provided that problems proposed for investigation in space have from the outset a sound base in terrestrial science or technology and that the proposed experiments address scientific or technical problems and are not motivated primarily to take advantage of flight opportunities or capability of space facilities.*" (page 5, emphasis theirs).

2. Advantages of Near Zero Gravity Environment

The Academy Committee looked at all the variables which it could identify in space and found that the only advantage to materials processing in space was the near zero gravity condition,[23] concluding that other aspects of the space environment (temperature, ambient vacuum and radiation) either had no effect on materials or their effects could be duplicated on Earth. The Committee identified four areas in which a near-zero gravity environment would be useful in experimentation: the possibility of reducing or practically eliminating buoyancy-driven natural convection for substantial periods of time; the possibility of testing experimentally the basic assumptions necessary in theoretical models of systems in which complicated patterns of fluid density variation are inherent; the possibility of reducing or practically eliminating the settling of particles for substantial periods of time; and the possibility of levitating and isolating larger samples for containerless processing.

To gain a perspective on the overall viability of a materials processing in space program, the Committee chose one technology, that of growing semiconductor crystals in space for commercial use, for detailed examination. As outlined in a previous section of this chapter, a number of crystal growth experiments had been performed during

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[21] Originally the Academy had planned to do two materials processing in space studies, the first on the scientific and technological aspects, the second looking at the commercial aspects of the field (proprietary rights, etc.). As of December 1980, the second study on commercial aspects had been deferred indefinitely.

[22] NASA Seeks Industry Space Processors. Aviation Week and Space Technology, Jan. 26, 1976, p. 55.

[23] Some gravitational acceleration is caused by human movement within a spacecraft, movement caused by thrusters used to maintain correct orbital attitude, and the like. Therefore in an earth-orbital space station one encounters "near-zero gravity" rather than zero gravity.

the Skylab missions. Although the Committee agreed that the results obtained on Skylab showing that crystals of superior characteristics could be produced in space were valid, the Committee stated that "these results are not sufficient to permit concluding whether growth in space of crystals for commercial electronic devices is or is not viable." (page 37) The materials used in the Skylab vapor-growth experiments (germanium-selenide (GeSe) and germanium-telluride (GeTe) are not expected to be used in practical electronic devices, according to the report, nor is the growth technique used expected to be used for growing those materials that do have significant practical applications. Another material, indium antimonide (InSb), was also considered commercially unimportant by the Committee since it is used only in a small number of specialized infrared detectors, and the growth method (directional solidification in a closed tube) is not used for production of commercial electronic devices. Therefore the Committee concluded that it was "impossible to extrapolate the results of the InSb, GeSe, or GeTe experiments to specific materials or processes used or planned for use commercially or to predict any specific advantages of processing those materials in a low-g environment." (page 38)

In the early 1970's, space-based electrophoresis was represented as being of considerable potential benefit in the production of vaccines,[24] although more recently focus has shifted to the production of isoenzymes such as urokinase. This field received very little support from the Academy, based on the thesis that electrophoresis studies on the ground did not yet provide a solid basis for investigations in near zero gravity. Calling the results from the Skylab and ASTP experiments "tenuous," the report suggested that further funding be spent on identifying what role gravity (and other parameters) plays in the electrophoretic process through ground-based studies. "In terms of what is now known, the Committee concludes that there is no pressing need for an enlarged trial of electrophoresis in space." (page 30)

3. Organizational Recommendations

The Committee also issued recommendations on the organizational structure of a materials processing in space program. It suggested that the program be conducted in two phases. During Phase One, which would last for about five years, NASA should make every effort to include other agencies in the planning of appropriate experimental programs which would clearly delineate the potentials and limitations of materials processing in space, and provide NASA with necessary experience in developing facilities of maximum value to the scientific and engineering communities.

Phase Two would see NASA as operator of the space shuttle as a national facility for materials processing, with industry and universities providing requisite funding for experiments rather than NASA. This phase would necessarily develop only if materials processing in space proved to be viable during Phase One, and in the Committee's view, if adequate funding is not supplied by the outside community, Phase Two should be discontinued.

In response to the Academy's recommendation, NASA established a Commercial Space Processing Development Office at its Marshall

[24] For example, see David Keller's statement in: U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. Space Shuttle Payloads, part 2. Hearing, 93d Congress, 1st session, Oct. 31, 1973. Washington, U.S. Government Printing Office, 1973. pp. 91–101.

Space Flight Center to conduct studies of institutional, legal and economic issues involved in private sector space processing activities, and to handle negotiations with any company that might express interest in long-range joint undertakings with NASA.[25]

4. General Conclusions of the NAS/SAB Study

The overall conclusions of the Committee were that the instances in which the low-gravity environment of space is likely to be important for materials processing in space will be few and specific, and that it found no examples of economically justifiable processes for producing materials in space. The Committee recommended that NASA not emphasize materials production (as opposed to processing aspects of the program). The Committee also emphasized that "NASA must keep in mind that one of the proper roles is the development and operation of singular facilities in response to and not independent of the scientific and technological community."

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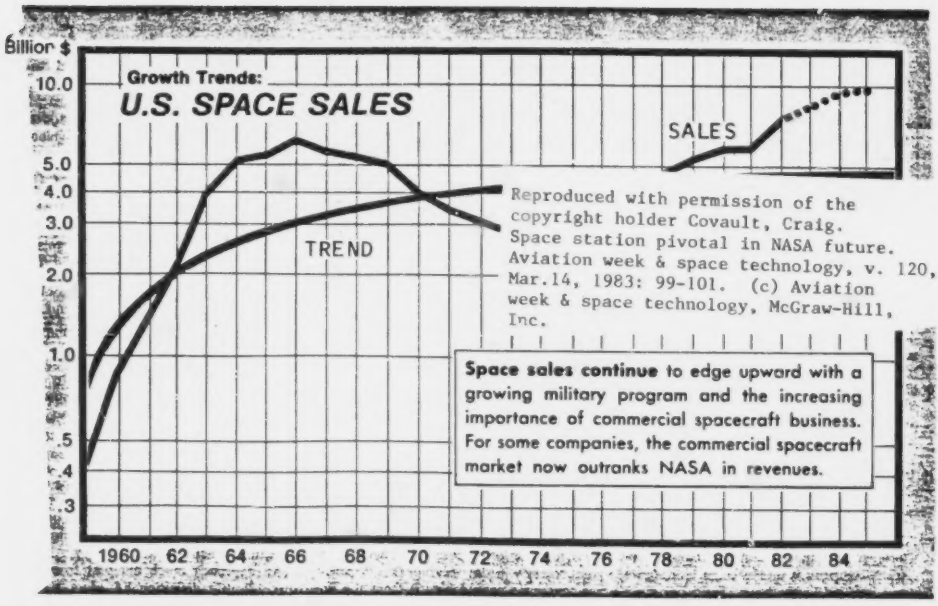
[25] Anthony Calio. In U.S. Congress. House. Committee on Science and Technology Subcommittee on Space. Science and Application. 1980 NASA Authorization (Program Review). Hearings. 95th Congress, 2d session, Sept. 25, 26, 27, 1978. Washington, U.S. Government Printing Office, 1978. p. 176.

D. Space Station



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Aviation Week & Space Technology, March 14, 1983

Space Station Pivotal in NASA Future

By Craig Covault

Washington—National Aeronautics and Space Administration space station studies have matured to a point where findings and decisions made over the next eight months could affect the character of the agency for the next 10-20 years. NASA managers forecast station development would substantially change the character of U. S. space operations and the structure of NASA itself.

NASA would like to start a $5-6-billion station development program with significant funding beginning in Fiscal 1986 and continuing at $1 billion a year until an initial operating capability is reached about 1991.

Although participating in detailed station justification studies, the Reagan Administration has not committed to station support. Presidential Science Adviser George Keyworth has characterized the station concept as an "unfortunate step backwards." These indicators do not mean the concept is on a dead end street, however, because many factors, including strong political issues, will be part of the approaching station decision.

The structure of NASA in the era of station development also will be an issue. Even with $1 billion a year in station development funds, many agency managers believe NASA would still be underutilized. Some managers also believe the only way out of this excess overhead is to close one or two NASA centers and possibly consolidate shuttle mission control activity at Kennedy Space Center. A space station may not require a Johnson Space Center massive control center—the concept is for it to handle most of its control activities right on board.

Space station factors important to near-term decision making and long-term NASA planning are:

- Distributed system.
- Justification base.
- Man-tended satellites and platforms.
- Manned science operations.
- Unlikely Defense Dept. participation.
- Commercial participation.
- Science and applications users.
- Corporate reluctance.
- New start timing.
- Station task force strategy.

Space station task force studies show a U. S. station will not look like Skylab or the Soviet Salyut but will be a set of space-based systems, both manned and unmanned. In all cases the "station" would be evolutionary with a small, habitable core functioning as a manned operations base to service spacecraft on platforms distributed either near or some distance away from the habitable section.

No dominant user or justification has been found to warrant a large U. S. station system. The justification must come from an aggregate of users, NASA station task force studies show.

Station task force data also show that the ability of manned crews to tend satellites and platforms within reach of the habital section offers benefits in retrieving commercial products, adjusting instrumentation and replenishing consumables. The "man-tended" approach for a broad series of spacecraft is a key station justification in current studies. It enhances numerous existing missions and enables others to be done for the first time.

Use of man to perform extensive onboard scientific work in a space station has been found to be a minimal justification for most station activity. For life sciences work and some technology work, a manned presence is necessary, but for most science the man can be located re-

motely. "It would be a bit of a swindle to try and persuade people not familiar with the program that science really requires man to be around all of the time," Stephen S. Holt, science representative on the station task force, said. "Telepresence, with man in the loop but not on site, will do fine in many areas."

The outlook is poor for extensive Defense Dept. participation during early station evolution because the department, although actively studying military station uses, has not found high-priority uses for a permanently manned facility and has serious concerns about survivability.

Space task force and contractor study data show both aerospace and nonaerospace industry interest in a space station system, however. There is fairly high interest in a station-based industrial research laboratory that could be used by a number of companies. At least one aerospace company is interested in funding its own station compartment for proprietary work, station task force managers said. Commercial interest, however, is no more dominant than that of any other potential user groups. The companies do not want to put big money up front when station risk is high. They are more interested in paying for facility use, once the government puts facilities in place.

Use of a station as a base from which to tend and replenish large free-flying observatories or Earth-observing platforms has emerged as a strong concept in space station task force studies. Which disciplines benefit first will depend upon whether equatorial or polar basing is selected initially. The plan is to evolve into operations in both orbits.

Some managers believe station user requirements and interests have been hard to assess because the aerospace companies have not yet put their best options on the table for fear of tipping their hand at a point so early in the program that competing companies would benefit from the information. The same reluctance has been part of the reasoning of companies wishing to exploit space for commercial purposes, some managers believe.

Although NASA does not plan to request significant station development money until Fiscal 1986, it is possible a formal space station line item could appear in the Fiscal 1985 budget. In addition, the White House Senior Interagency Group (SIG) for Space has a station working group, and data acquired by that body could lead to an Administration statement on the station within the next year.

Office of Management and Budget remains unconvinced a station is a good idea, however. One OMB view is the most NASA will receive is approval to move ahead with unmanned platforms to be serviced by the shuttle, but not a permanently manned facility.

An approach much different from the space shuttle definition 15 years ago is

being used by NASA station managers. Instead of designing the vehicle and telling the user community to find ways to exploit it, the station approach is to define across-the-board requirements, let those requirements determine the function of individual station elements and then have those functions influence how the hardware is built.

The approach has been difficult to grasp by NASA and contractor managers more familiar with hardware. Part of the requirements data base is being assembled by eight aerospace corporate studies. During their midterm review last January, some companies were graded poorly for trying to tailor requirements too much to fit what they thought would be an appropriate operating mode. The studies are being completed and data compiled by review groups and the Defense Dept.

Next month the station task force will take all those requirements and at either the NASA Langley or Wallops Center will meet for about two weeks merging these requirements into one or two sets of time-phased mission requirements.

"The reason we want to do that is to give us some feel for what are the design drivers for the early and late phases of a potential space station," John Hodge, director of the station task force, said.

"The crucial point is that the design will be incremental, but each increment has to serve a major useful purpose," Daniel H. Herman, deputy to Hodge on the task force, said. "In April we will determine what crucial increments will yield what station functions."

As the mission requirement sets are about to be completed, the NASA centers are just completing their first round of work on about 30 of nearly 300 potential trade studies identifying the work needed to be done to reach certain system goals like electrical power in a space station.

With the mission set and trade study data, the station task force hopes by midsummer to make preliminary conclusions on the functional pieces of the station that will be needed first and how they will fit together. This will not relate to a single habitable facility but to the station system as a whole, manned and unmanned elements.

The station task force describes the definition of capability of each element and its relationship to other elements as "station system architecture."

The first significant version of station architecture is expected by this summer. Hodge hopes that by year's end the station task force will be close to determining

formal U.S. station architecture. Even with those data, the planning will still not be at the design phase. Since the important requirements that will govern the nature of a U.S. station system will remain embedded as individual elements in the trade studies until after the April session, it is not now possible to identify what the system will look like or its major uses.

Hardware Concept

Engineers and planners are used to working the opposite way, with a hardware concept much earlier. In this case that approach will not work.

"It is very difficult to hold these people back," Hodge said.

The definition is proceeding under NASA headquarters control, not at either the Johnson or Marhsall centers, NASA's principal manned flight focal points. This has caused consternation among some managers, especially at Johnson.

Johnson's original space operations center concept involved more of the traditional approach toward system design with a significant amount of early hardware concepts. The station task force has strived, however, to avoid station configurations at this planning stage. Task force members believe the important contribution Johnson has made to the planning effort is a concept of station operations much broader than more tradational Skylab/Salyut station operations concepts.

Marshall also focused on configurations, stressing the use of existing hardware in dispersed platforms operating in the vicinity of a habital module. Marshall's contribution has therefore been the "distributed system" concept.

The distributed system has resulted in use of a concept called "energy proximity," meaning a part of the station operations separate from the habitable module but in an orbit easy to reach from the station base area.

System Development

The distributed system and energy proximity concept will require NASA to develop a teleoperator maneuvering system, a moderately sized propulsion stage that can carry hardware or crewmen to different elements of the distributed system. The device would not be as large as the orbital transfer vehicle eventually necessary to make longer trips between widely separated orbits, or from low orbits to geosynchronous orbit.

Since the teleoperator maneuvering system would be useful for a wide range of shuttle applications in addition to station work, NASA expects to develop it separately from the space station budget.

The agency determined two or three years ago that a true national station concept required operations in both polar and equatorial orbits. Defense intelligence and Earth applications payloads need to fly in polar orbits while most science, commercial and transportation-oriented space missions need the more easily reached equatorial orbits.

A question to be addressed soon, important to the station and NASA's long-range future, is whether to go polar or equatorial with the initial station elements. Station task force members will take three options into the April meetings and hope the requirements data will direct them toward one mission model area. The options are:

- **Equatorial first**—One option would establish operations at about 28.5 deg. equatorial inclination followed by establishment of polar orbit operations. Once station-type operations were in both orbits, a large orbital transfer vehicle (OTV) would be developed as the third sequential element in this operation.

- **Higher-priority OTV**—The second option is establishment of the station first in equatorial orbit, followed by OTV development. Polar operations would follow third. The sooner the OTV is developed, the sooner manned geosynchronous orbit and station-supported planetary missions can be started.

- **Polar priority**—The third option is to develop polar orbit space station facilities first, then equatorial orbit facilities followed by the OTV. This option would emphasize defense intelligence and a wide range of Earth applications missions first.

The concept of satellite servicing and man-tended systems would come much faster with an equatorial system. Space Telescope, for example, would probably be serviced in space over a 20-year period instead of being returned to Earth every

Workforce to Grow

Stevenage, England—British Aerospace Dynamics expects to increase its space-oriented work force from the present 1,600 employees to 1,800 by the end of 1983 and to 2,000 in three to five years to handle the increasing amount of space-related work it is receiving.

The work force already has grown from 1,400 since 1982.

Additional manufacturing and development space is being acquired in Stevenage, although the exact size of the facilities expansion has not yet been determined.

Work is done here and at the company's factory in Bristol. Company officials said there are no plans to expand to other sites. Economics, according to the officials, dictate that as much work as possible be done at existing sites.

five years for maintenance as currently planned.

The current Earth-return maintenance requires two dedicated shuttle flights for each ground servicing. In addition, large telescopes starting out as shuttle payloads would be left in orbit as servicable facilities. The solar optical telescope is a good example.

These are the types of missions helped by a station. A mission type made possible in the first place by such permanent orbital support would be large advanced facilities, such as infrared telescopes that need cryogenic cooling.

The Infrared Astronomical Satellite (IRAS) mission now making new discoveries in deep space has only about a one-year cryogenic helium supply before the spacecraft will cease operations (AWAST Feb. 28 , p. 21). With this rapid cryogenic depletion rate, such spacecraft can never perform the role of ongoing observatory, providing both cost and science benefits. If serviced in space, however, long-life systems can be designed and flown for years at a time.

Spacecraft Refueling

The only serviceable spacecraft currently operating in polar orbit are U. S. Air Force digital imaging reconnaissance spacecraft and an occasional film-based imaging reconnaissance spacecraft. It might be useful to refuel the digital spacecraft and refuel and reload film on the film satellites in the future.

"Basically if we go polar orbit as the first option, it will be an entirely new ball game. There are few serviceable spacecraft in polar," Holt said. "But if you go polar there are a number of Earth and atmospheric viewing instruments that would make a lot of sense being put together as one giant coordinated observatory."

One such concept has been designated System-Z. System-Z would be a large platform that contains a whole battery of Earth viewing instruments on a large serviceable platform. The concept is to have digital-imaging, microwave, radar, oceanographic, atmospheric and other instruments all taking coordinated data. The data products would then flow to a central distribution facility on Earth where multiple-user communities could procure the data.

"The whole emphasis in polar is a large platform instead of a lot of little free flyers being serviced in the way they would at 28.5 deg. orbit inclination," Holt said. In polar orbit the relatively small number of platforms would carry a large number of instruments to be serviced, as opposed to the equatorial orbit, where a relatively large number of spacecraft could be serviced, each carrying more specialized instruments.

Station Support

NASA station planners believe both polar and equatorial orbits will eventually support station activity. The question is where will it be established first.

Other factors that contractors and other groups studying station requirements have been asked to include in their assessments are:

- **Inheritance**—Any station must be capable of allowing a smooth inheritance of hardware from existing programs such as Spacelab.
- **Manned requirements**—Science and research areas that require direct manned participation, such as life sciences and materials processing, must have near-continuous availability of man, not just visitation by man.
- **Technical intervention**—Most disciplines benefit more from manned technical intervention for servicing and construction than they do from manned science interaction.
- **Technical capability**—Manned technical intervention need only be occasional, such as once every several months or years, but the intervention period itself could be lengthy, extending several days or weeks, such as for construction, assembly and checkout of new hardware.
- **Existing spacecraft servicing**—Several new spacecraft coming on line such as Space Telescope, Gamma Ray Observatory and the Advanced X-ray Astronomical Telescope will be available as a "cluster" of spacecraft in need of service at about 28.5-deg. inclination.
- **Platforms**—Free-flying platforms associated with the station are planned for early development but are not yet defined as to how large or what discipline they will involve. Their development will be somewhat contingent upon what type of continuous manned station activity NASA is able to achieve early in the development of the new national space facility. □

-Research News

NASA Wants a Space Station

Proposals range from a multibillion dollar space city to a low-budget platform; but what do the users want?

"We have a highway to space!" astronaut Thomas K. Mattingly proclaimed after the fourth and final test flight of the space shuttle Columbia. And now that the shuttle is officially ready for use, he added, "we need to build the city"—a permanent space station in low earth orbit.

Mattingly is not alone in that sentiment. The National Aeronautics and Space Administration (NASA) as a whole wants that space station very badly. It would be the agency's next major mission, the heir to Apollo and the shuttle. NASA administrator James M. Beggs suggested it as such in his confirmation hearings last year, and since then has been touting the idea at every opportunity. The agency fought for, and obtained, favorable wording for the idea in the Reagan Administration's new space policy (*Science*, 23 July, p. 331). In May a ten-member task force was organized at NASA headquarters to coordinate further planning. And next year the agency hopes to include more than $10 million for space station development in the fiscal year 1984 budget, which goes to Congress in January. NASA estimates the station will ultimately cost some $3 billion to $5 billion, with the initial modules reaching orbit about 1990.

NASA's fervor for the station stems in part from institutional need. Without some kind of new mission the agency sees itself degenerating into a kind of high-tech trucking company, with nothing much to do but launch payloads for other people. But it also stems from a vision of the space station as the logical next step after the shuttle. Agency officials are fond of pointing out that the space station idea came first. The shuttle was conceived in the 1960's simply as a cheaper way of getting up there and back. Now that the shuttle is operational, says deputy administrator Hans Mark, it is time to go back and finish the original plan.

Unfortunately for NASA, however, it is hard to imagine a worse economic climate for proposing a multibillion-dollar space city—especially since a great many people still see every space endeavor in the image of Apollo: massively expensive projects pursued for little else but national glory and NASA's continued existence. Senator William Proxmire gave Beggs a lecture on the subject in hearings last May: "I am concerned that [the space station] will proceed regardless of the real need for such a program because your agency needs it more than the country needs it."

Among scientists, meanwhile, there is a widespread fear that the space station would be another shuttle, with delays and cost overruns that once again savage NASA's science and applications programs. As one high-ranking House staffer puts it, "I think there will be support for the space station as a long-range goal—if NASA doesn't have to give up everything else to get it."

On the other hand, many of these skeptics concede that a modest platform, focused on specific user needs, might prove very useful. It could serve as a research platform in fields such as astronomy, materials science, and remote sensing. With further development it could also serve as a transportation hub for moving communications facilities into geosynchronous orbit, or for launching a new generation of planetary spacecraft. Presidential science adviser George A. Keyworth, who has been highly skeptical of the more ambitious space station concepts, told *Science* that such a low-key, step-by-step approach has a reasonable chance of White House approval.

The question, then, is not whether a space station per se is worth having. A space station should be a tool, not an end in itself. The real question is whether that tool is worth the cost.

The answer seems to be "Yes," although that judgment depends on just how well NASA fits the station hardware to the needs of users. Unfortunately, NASA generated considerable confusion on the matter during the last year, with different segments of the agency advocating very different things.

Broadly speaking, there are two points of view. On the one hand, there are the veteran engineers who remember the glory days of Apollo. They stress the importance of manned operations in space. Their ideas for a space station are epitomized in the Space Operations Center, or SOC, a conceptual design produced by the Johnson Space Center in Houston, Texas. The SOC features habitat and workshop modules for 9 to 12

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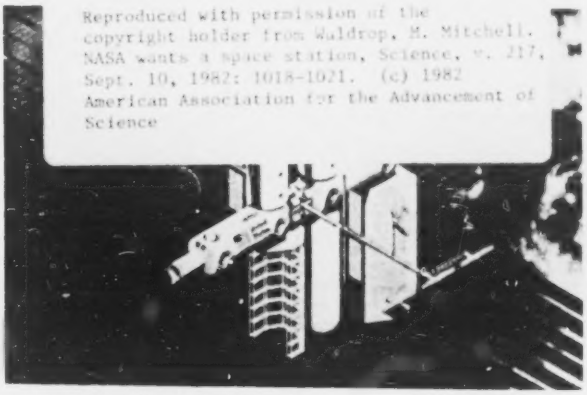

The Space Operations Center concept

The design includes solar panels, habitat and workshop modules, construction booms, fuel tanks, and spacecraft hangars. All the modules would be brought up by the shuttle and assembled in space.

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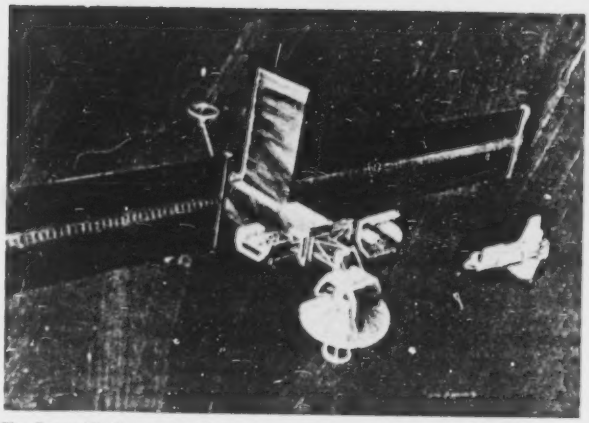
people, construction booms for assembly of antennas and other large space structures, and fuel tanks for a separate Orbital Transfer Vehicle that would take cargo brought up to the station by the shuttle and ferry it into the 35,900-kilometer geosynchronous orbit. SOC would cost about $8 billion over 10 years.

For a while, the Johnson public relations team managed to convince a lot of people that SOC *was* the space station, even though NASA was actually nowhere near a final design. In fact, top agency officials have all but disowned SOC. Space assembly and orbital transfer might be crucial in the 1990's, but in the current economic climate SOC's $8-billion price tag was only giving ammunition to critics of the station. Besides, the emphasis on SOC was obscuring the fact that there are other ways of building a station, ways much more congenial to cost-conscious Washington.

The most prominent example was the Space Platform design produced by Johnson's rivals at Marshall Space Flight Center in Huntsville, Alabama. The platform epitomized the task-oriented point of view of NASA's scientists and applications people. In its simplest, unmanned form, it would be little more than a set of solar panels for power, some internal electronics, and a number of sockets for instrument pallets taken right out of the shuttle payload bay. Manned modules and construction equipment could be added later, if needed. The Huntsville group estimated that the first space platform would cost about $750 million, with replicas costing another $400 million apiece. While such platforms could hardly be called cheap, the Huntsville planners argued that the price would be low enough for NASA to contemplate building several and specializing each to a different purpose.

Back at NASA headquarters, however, Beggs and his associates saw little chance of getting their space station unless they could resolve the confusion and come up with something all the potential users could support. Both the Marshall and the Johnson plans were too specialized, it was felt. Thus, both designs were scrapped, and in May the Space Station Task Force was formed to reconcile the disparate points of view into an all-NASA design.

Task force leader John Hodge seems well aware of NASA's oft-criticized tendency to plunge ahead with hardware development before it thinks much about the users. That impulse prevailed in the shuttle program, he points out, and as a result the agency spent the late 1970's in an embarrassing scramble for customers.



The Space Platform concept

Shown here with the space shuttle in the far background, the platform would essentially just provide power and stabilization for instruments mounted in pallets brought up in the shuttle's payload bay.

It is a prime source of apprehension and skepticism about the station. "So we're trying to take an entirely different approach," he says. "We're saying, To hell with the configurations, what are the requirements over the next 25 years?"

Thus, Hodge is asking eight aerospace companies to take a fresh look at the scientific, commercial, and military missions for a station. Only after the appropriate missions are identified will each of the eight draw up new conceptual designs. "Then you compare them and try to take the best from each," he says. By mid-1983 the results should be in hand and the agency should be ready to begin technology development and trade-off studies.

Some user needs are already fairly clear. A good example is space astronomy. During the past decade, enormous strides have been taken with short-lived satellites such as Uhuru, Einstein, and the Solar Maximum Mission, and the astronomers are hungry for more. Space Telescope, due for launch in 1985, will allow them to study how faint, distant galaxies and quasars began forming in the aftermath of the Big Bang. Solar Optical Telescope (SOT) will ride in the shuttle bay to image the fine structure of flares and sunspots—structure obscured by the atmosphere, but crucial for understanding solar activity, the solar wind, and their impact on the earth. SIRTF, the cryogenically cooled Shuttle Infrared Telescope Facility, will use its freedom from infrared-absorbing water vapor to peer into molecular clouds, where stars are being born, and into the core of our galaxy, where there may be a supermassive black hole (*Science*, 21 May, p. 838).

When the National Academy of Sciences recently made its recommendations on astronomy's needs for the 1980's [the "Field Committee" report (*Science*, 16 April, p. 282)], well over half the programs involved new instruments in space. At the same time, the report strongly endorsed the use of a space platform for astronomy.

"There are few, if any, astronomical missions that would not be better done from a platform than from the shuttle," says committee member Harlan J. Smith, chairman of the astronomy department at the University of Texas, Austin. He points out that instruments mounted in the payload bay will have only about 7 days in orbit before the shuttle's fuel cells run out of power. Then they will have to come home. Compare that to leaving the telescopes on an independent space platform, where they could stay in space for 6 months or a year.

"It's an order of magnitude more exposure time for only a very slight additional cost," says Smith. Thus, more astronomers could use the instruments—astronomers never have enough telescope time—and an instrument like SOT, for example, could monitor the sun continuously for flares and other transient phenomena that it might otherwise miss. Besides, he says, a high-resolution telescope would be more stable on a

platform than on the shuttle, where astronauts would shake it slightly every time they moved.

Each payload could be placed on its own free-flying satellite, of course, just as the Space Telescope will be. But each would then have to have its own hardware for pointing, stabilization, communications, heat dissipation, and photovoltaic power. A platform would centralize those functions. William C. Snoddy, deputy director of program development at Marshall Space Flight Center, estimates that a typical scientific payload could operate for 6 months on Marshall's Space Platform at a cost of roughly $30 million—less than one-third as much as the cost on a free-flyer, and some 30 percent less than the cost on the shuttle. (The $30 million includes a portion of the cost of the platform.) Clustering the payloads would also make it easier for visiting shuttle astronauts to top off the cryogens, make repairs, or replace one set of instruments with another. They could service many payloads at once instead of chasing individual satellites all over the sky.

> The question is not whether a space station per se is worth having. A space station should be a tool, not an end in itself. The real question is whether that tool is worth the cost.

After astronomy, another prime mission for the space station is zero-gravity materials processing. There is already intense interest in both the fundamental science that can be done and in the potential commercial payoff. On the first flight of Spacelab in 1983, for example, the European Space Agency will devote 33 out of 77 experiments to materials science. NASA has an active program centered at Marshall in Huntsville. And private money is beginning to come into the field.

"We want to isolate the effects of gravity so we can better understand fundamental processes," says Lowell K. Zoller, head of the materials science program at Marshall. Six different crystallization processes are used commercially, he points out, and all of them are affected in fundamental ways by gravity. Hundreds of metal alloys have never been made on the earth because the components are immiscible and separate before the melt can cool. There are any number of ideas for making ultrapure materials that never come in contact with a container wall. "We'll need to ferry hundreds of specimens back and forth," says Zoller. "We're really looking forward to the station so we can get a lot of work done instead of one shot at a time."

The most dramatic example of the field's commercial promise is the collaborative effort of McDonnell Douglas Astronautics and the Ortho Pharmaceuticals Corporation division of Johnson & Johnson. During the past 6 years the partners have spent several tens of millions of dollars to develop the techniques of zero-gravity electrophoresis, with the ultimate goal of producing pharmaceuticals commercially in space. Candidates include insulin-secreting beta cells, interferon, epidermal growth factors, growth hormones, and as many as 40 others.

On the fourth shuttle flight a McDonnell Douglas/Ortho test unit verified that zero-gravity electrophoresis yields 400 times the output and up to 5 times the purity as the same process on the ground. The researchers are jubilant. If subsequent tests continue to go well, a production facility could be in orbit by 1987.

"We see some distinct advantages to having it on a space station," says David Richmond, electrophoresis program manager at McDonnell Douglas. Again, the main problem with the shuttle is its time limitation: "You wouldn't build a factory on Earth twelve times as big as you need just so you could run it for only one month of the year," he says. It would be much better to have a continuous process. And McDonnell Douglas finds significant improvements in cost in using the station instead of a free-flying satellite.

In a third field, communications, a space station would have little direct application because the satellites used for television, direct broadcast, business communications, and the like all occupy geosynchronous orbit, 35,900 kilometers up. The shuttle and any space station launched and serviced by the shuttle, is limited to a maximum orbital altitude of about 400 kilometers.

But a space station in low earth orbit could still prove useful in an indirect sense. Burton I. Edelson, formerly senior vice president of COMSAT and now NASA's associate administrator for space science and applications, points out that satellite communications traffic is projected to increase by a factor of about 30 between now and the end of the century. "So we will have to make optimum use of every point in the geostationary arc, and optimum use of every frequency," he says.

One solution would be to cluster very large antennas on a platform in geostationary orbit, he says. This would obviously help with overcrowding. Just as important, the large antennas would no longer have to broadcast to a whole hemisphere. Instead they could transmit spot beams, sending one message to California while—at the same frequency—sending something totally different to New York. "It would provide three times the information-carrying capacity for a given investment," says Edelson.

The problem is that the platform he envisions would have a mass of about 5000 kilograms, five times that of the largest communications satellites today. There is no way to launch such a thing directly. So the shuttle will have to bring it up in several loads, says Edelson, and astronauts will have to assemble it in space. "And then because it is precision equipment it will have to be aligned," he says. "Then it has to be mated to the booster that will take it to geosynchronous orbit." All this will require a staging area, and the logical place for that is a space station.

Back at NASA headquarters, Hodge and his task force are faced with the problem of turning these user requirements, and others, into hardware that satisfies everyone. Astronomers, for example, would clearly be happy with a Huntsville-style platform, while the construction of Edelson's antenna farm would require something very much like a SOC.

Moreover, the initial station, however modest, has to allow for growth. "We cannot envision all that we are going to do," says Hodge. One approach might be to drop the idea of a single space station, and instead imagine it evolving into a cluster of structures. At the center would be construction facilities and a manned, SOC-like module, from which astronauts would go forth to service nearby platforms specialized for such uses as astronomy or materials science.

Another problem—and, at the moment, one of NASA's most potent political problems in selling the station—is making sure that the costs can be kept under control. The station does have one key advantage, say agency officials: it is modular. "We are not in a position where we have to go to the President in a very difficult budget year and say, You

have to spend so much on a space station," says Hans Mark. "You can spend as much or as little as you want. It just depends on the time scale and the degree of urgency."

Meanwhile, Beggs has been sounding out the Europeans about cooperative financing of the station, with some success. And Major General James A. Abrahamson, head of NASA's Office of Space Flight, says that two groups have already been in contact with him about private financing of a platform for zero-gravity materials work.

Still another question is whether the station should be manned. NASA's belief in "Man in Space" often takes on a mystical quality: "I won't believe it's really a space station unless it's got a man on it," says associate deputy administrator Phillip E. Culbertson. On the other hand, as Wilfred Mellors of the European Space Agency points out, "You don't want the man to be there just to take care of the life support system." The presence of humans on a space station would add greatly to its flexibility, but also to its cost and complexity. NASA needs to do some hard thinking about when humans will really be needed in space and when machines can do just as well.

Then there is the question of the military's role on a space station. NASA, which needs all the support it can get on the project, has been courting the Pentagon actively. "It would be inappropriate to say they're highly enthusiastic," says NASA's Mark T. Nolan, a member of the space station task force. It is a very new idea, after all. "But the Air Force has formed a working group in the Space Division and interest is rapidly picking up."

Nobody is planning for the initial station to carry weapons, he adds. The details are classified, but in the near term the military missions on a station would tend to look a lot like the civilian applications: development of large antennas, for example, or satellite repair. So doing both on the same station should not be difficult.

In the longer term, however, the Air Force is very interested in such things as space-based lasers and particle beam weapons. Should they prove workable, and should the Air Force want to deploy them on a space station—and it is not at all clear that such a thing would be sensible—the compatibility problem would become severe, Nolan says. For one thing, private companies such as McDonnell Douglas and Ortho would hardly want to put their production module on a military target. For another, the Pentagon would hardly want to allow visits by foreign nationals, which would seem to preclude international participation in the station. One obvious solution, if the money were available, would be to build separate stations for military and civilian uses.

Does the United States really need a space station? In the last analysis the question is not technical, but political. As political scientist and space historian John Logsdon of George Washington University points out, "The only reason to build a space station is if there is a national decision that space is worthwhile—and that the space station is the best way to do the things you want to do."—M. MITCHELL WALDROP

Current NASA Space Station Planning

By PHILIP E. CULBERTSON
NASA Headquarters

At their confirmation hearings in June 1981, the men President Reagan nominated as administrator and deputy administrator of the National Aeronautics and Space Administration were asked what they thought the next major step in space should be. James M. Beggs, the administrator-designate, responded: a space station. Hans Mark, the deputy administrator-designate, agreed, noting that the space agency would need to work toward a permanent presence in space. Now firmly in charge of NASA, they have directed the agency to undertake planning that will lead to a space-station program for consideration by the administration and Congress as a major new initiative in space. This article reviews the steps taken to fulfill their directive, sketches actions planned for the future, and discusses a number of issues that have arisen as NASA has undertaken this task.

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Off and on for nearly twenty years NASA has weighed the many factors involved in operating a permanently manned facility in low Earth orbit (F-1). It has examined many space-station concepts. And in 1973 the agency launched our country's first space station, Skylab, based on Apollo technology. Skylab clustered several major assemblies —workshop, airlock, docking adapter, solar observatory, and command-and-service module (F-1). Three-man crews rendezvoused and docked the Apollo command module with the station on three different occasions, with mission stay times of 28, 59, and 84 days.

Skylab demonstrated what we now take for granted: that man can function effectively in space, essentially at zero-*g*, for extended periods. It dramatically illustrated the usefulness of a crew to make repairs (to the electrical and thermal systems, compensating for damage to both during launch). It also demonstrated the value of a manned scientific laboratory in orbit. Results from eight different solar telescopes mounted on Skylab's Apollo Telescope Mount dramatically advanced our understanding of the Sun.

Two years after Skylab, the idea of a permanent station received in-depth attention: MOSC, the Manned Orbital Systems Concept. Studied under contract to NASA by McDonnell Douglas Astronautics in 1975, it emphasized science and applications for extended-duration missions. The approach taken in this study—focusing on mission requirements before configuration analysis—NASA has adopted today in order to be fully responsive to user thinking. We are now reviewing system characteristics and capabilities. MOSC geared requirements to science and applications. Today, the requirements are broader. They include national security, commercial work, and an "operations" orientation—activities of a functional nature in support of space-based operations, such as servicing automated satellites and launching propulsive stages and spacecraft to higher orbits.

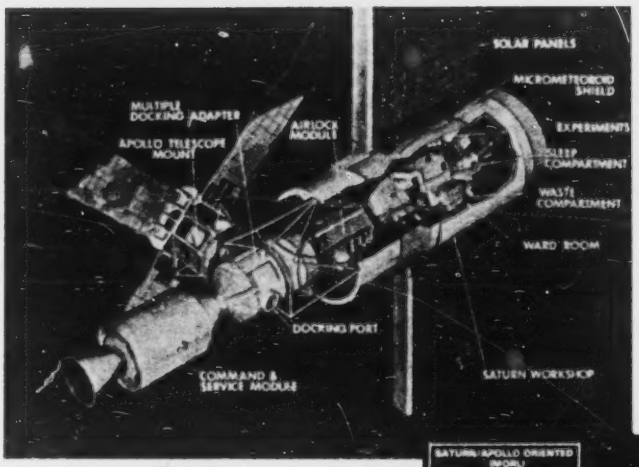
In the 1975 effort, the MOSC study team identified 46 Shuttle payloads as candidates for extended-duration missions, and grouped them into 19 payload combinations (T-1) based on equipment commonality and operational requirements. In turn, these drove MOSC design criteria, which may be summarized as follows—

—Support 720-day missions.

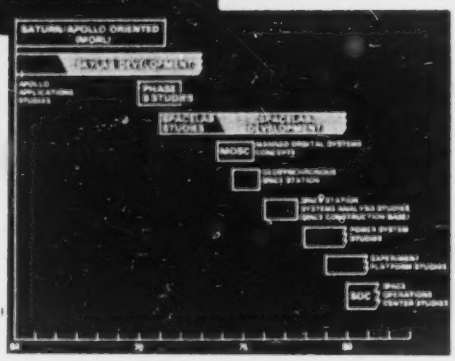
—Up to four specialists per payload combination.

—Payload power of 8 kw (supplemental to 10).

—Altitude/inclination of 230 n.mi./28.5°; 200 n.mi./90°.



F-1 Skylab explored space-station rudiments through five major sections: workshop, airlock, multiple docking adapter, solar observatory using the Apollo Telescope Mount, and command-and-service module. It was one stage in NASA's two-decades-long exploration of permanent manned facilities in space that is mapped below.



—Altitude/inclination-change capability of ±95 n.mi./28.5°.

—Orientation: all attitudes; vehicle pointing to 0.1° accuracy and fine pointing to be achieved by instrument gimbaling.

—Onboard disturbance less than $10^{-5}g$.

—Contamination control equivalent to 100,000-class clean room.

—Data management covering real-time 5-MHz transmission; recovery of hard copy, film tapes, and materials; and closed-circuit TV.

—Real-time communications to payload-control centers.

—Accommodation features: routine two-man EVA, scientific/equipment airlock, payload equipment fully accessible, and modularized payload carriers.

—Operational features: multiple simultaneously active payloads; return of all, part, or none of payload equipment; resupply of payloads and rotation of payload specialists; and double-ended universal docking provisions.

For budgetary reasons the MOSC concept was not pursued.

While we flew Skylab and explored future space-station designs, the Soviet Union systematically pursued development of a permanent manned station. Beginning in 1971, with the launch of Salyut 1, through 1982 with the launch of Salyut 7, it has conducted space-station operations and studies that apparently have yielded both civil and military benefits. Despite certain limitations, the Salyut space station represents an impressive achievement. Salyut 6 (see F-2), launched in 1977 from Tyuratam, conducted successful experiments in remote sensing, biology and medicine, astronomy, and materials processing. It was visited by eleven different crews over its five-year working lifetime. Six crews included cosmonauts from the Soviet Bloc nations. Salyut 6 was deactivated in 1981—its windows were no longer clear—but the Soviets were ready with a more capable craft, Salyut 7, which they launched late this spring.

Though the Soviet Union embarked on the Salyut space station, relying on the existing Soyuz logistics system (a reusable logistics system was to be added later), we believed the U.S. should pursue both a

T-1 PAYLOAD COMBINATIONS IN 1975 MANNED ORBITAL SYSTEMS CONCEPT (MOSC) STUDIES

Payload	Description	Crew manhours	Weight, 10^3 lb Up	Down	Volume, cu ft	Avg. power, kw	Mission length, days	Altitude, n.mi.	Orbit inclin., deg
C1	IR astronomy	1,454	39	25	4,500	1	80	216	28
C2	UV astronomy	3,845	24	14	1,100	1	140	248	28
C3	Solar observations	4,187	15	14	1,000	1	160	216	28
C4	Space sciences 1	2,070	17	15	2,700	2	70	216	90
C5	Space sciences 2	1,608	16	12	2,200	2	80	216	90
C6	Amps/Earth science	3,280	24	14	1,900	2	120	200	90
C7	Space technology	884	26	17	2,300	10	40	200	28
C8	Cloud physics/technology	862	15	13	2,000	1	50	100	28
C9	Earth science 1	851	25	24	6,100	2	50	200	90
C10	Earth science 2	690	26	26	6,000	2	80	200	90
C11	High-energy astronomy/technology	1,118	20	20	1,200	1	70	135	28
C12	Life science/technology 1	6,289	100	66	13,300	10	400	200	28
C13	Life science/technology 2	4,039	81	60	10,600	6	200	200	28
C14	IR/UV astronomy	1,427	45	17	2,000	2	120	162	90
C15	UV astronomy, advanced	585	24	16	1,000	1	50	162	90
C16	Cosmic-ray lab	5,800	50	37	5,600	1	360	200	28
C17	LD life-science lab	23,200	39	34	2,600	8	720	200	28
C18	Advanced technology	493	8	7	1,600	2	45	200	90
C19	Space manufacturing	11,000	7	6	200	5	900	200	90

space station and a new logistics system, but the review of space policy in 1971 concluded that budgetary restraints would require us to choose one or the other. We chose new logistics, a space transportation system. Now, with the development of this transportation system winding down, the time is right for planning for completion of the overall system. Our planning of a space-station program will put the administration and Congress in a position to make an informed decision on the development of such a facility, its timing, and its overall relationship to national goals and requirements in space.

With a national economy under stress, with funds for new discretionary programs severely limited, why should the nation want to commit to a space-station program? Several reasons exist, each compelling.

A U.S. space station in permanent orbit would maintain well into the 1990s our position of leadership among spacefaring nations. As evidenced by the Salyut spacecraft and by the European Space Agency's Ariane expendable launch vehicle, this position no longer can be taken for granted. In conjunction with the Space Shuttle, a station would give us the means to operate efficiently and continuously in space. Like the oceans, space would become a medium in which men and women routinely conduct useful activities. The vast potential of space would be more fully realized and the preeminence of the United States ensured.

PHILIP E. CULBERTSON became NASA associate deputy administrator in November 1981. He serves as senior staff advisor to the administrator and the deputy administrator and directs NASA's efforts to formulate policy, strategy, and planning of a facility to provide a "permanent presence" of the United States in space. From 1979 to November 1981 he served as assistant for the Space Transportation System. Earlier he was deputy associate administrator for space transportation systems (technical), assistant administrator for planning and program integration, director of advanced manned missions, and the NASA representative in the 1979 A-Sat treaty negotiations. Before coming to NASA, Culbertson was with General Dynamics/Convair. He holds B.S. and M.S. degrees in aeronautical engineering from Georgia Tech and the Univ. of Michigan, respectively.

A space station program would stimulate the development of advanced technologies across many disciplines. It would permit entry of the private sector into space by providing a microgravity facility for development and then manufacture of commercial products.

A space station could give a new dimension to the nation's space-science program. An orbiting platform would give space scientists a permanent, dependable, and versatile facility for "man-tended" facilities such as the Space Telescope and, in combination with an orbitally based propulsive stage and an orbital propellant-tank farm, a staging base for instruments and systems needing launch beyond the confines of low Earth orbit.

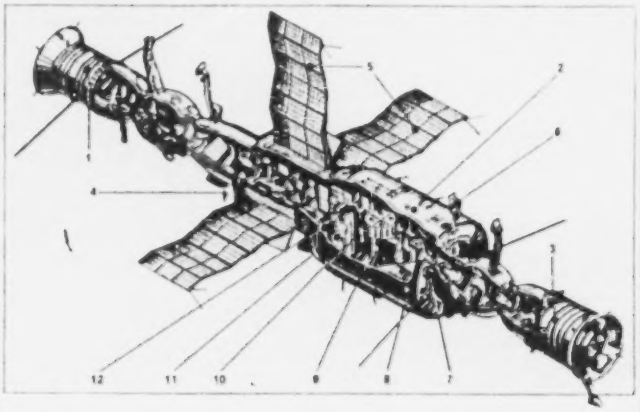
Lastly, a space station would enhance the nation's security. Readers of *Astronautics & Aeronautics* especially are aware of the role of spacecraft for a variety of national-security missions. The use of space is an essential element of our strategic posture. A space station would enhance our ability to perform these missions. At first, the station could be used to test and demonstrate new space-based systems. These systems would be developed by the various elements of our national-security establishment. Flown first aboard a general-purpose space station, they would assure the feasibility and practi-

cality of employing such systems aboard a manned orbiting space station. Later, a space station could be dedicated to national security users and employed operationally.

For the defense communities as well as the civil sectors, the space station would serve as both a laboratory and an operations base. As a laboratory, the station would provide for extended observations of the land and oceans for scientific, commercial, or defense purposes where man's presence for data integration, instrument selection and adjustment, and overall system maintenance is important. The station would enable man to participate in observations aimed in the opposite direction as well: outward to the Sun, the planets, and the stars. As an operations base, the space station could fuel and launch orbitally based propulsive stages, significantly increasing our ability to place satellites in geosynchronous orbit as well as to maneuver in low Earth orbit. The station could serve as a construction base for assembling and erecting large systems such as antennas, imaging systems, and other structures too large for launching directly from the ground. And the space station would serve as a base for maintaining and servicing free-flying unmanned satellites.

NASA's current planning focuses on the space station as a laboratory and an operations base, and on questions of requirements and architecture rather than of configuration. At this early stage of planning, the agency believes the temptation to configure a design must be resisted. Instead, we are examining constraints, systems interdependencies, growth alternatives, and limitations of flexibility.

Architecture implies a plan that defines space-station boundaries, functions, and elements. To assist in our understanding of space-station architecture, NASA is considering the concept outlined in F-3: a manned base coorbiting with several unmanned laboratories, facilities, or small platforms dedicated to specific missions, of a scientific, applications, commercial, or national-security nature. All the platforms would be delivered to orbit by the Shuttle and be Shuttle-retrievable. They would be unmanned but man-tended, either by the Shuttle or from the manned station. This station concept would consist of a docking hub, a power/utility module, and a habitat. A Teleoperator Maneuvering System based at the station would permit servicing of the platforms. In addition, manned laboratories, equipped on the ground for specific purposes, could be delivered to the station by the Shuttle. They would become a part of the station for a time, be operated by the onboard crew, and returned to Earth at the end of a mission. These labs would then be available for modification or re-equipping and reuse.



F-2 Salyut 6 orbital complex took the Soviet Union well down the road toward a permanently manned space station. Features of Salyut 6 are: 1. Soyuz spacecraft. 2. Orbital compartment. 3. Progress transport spacecraft. 4. Command console. 5. Solar panels. 6. Rendezvous antenna. 7. Correction motor. 8. Orientation motor. 9. BST-1M telescope. 10. Exercise treadmill. 11. Shower stall. 12. MKF-6M multispectral camera.

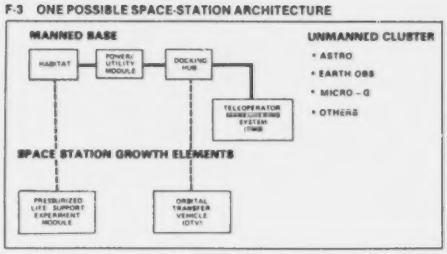
This model architecture is not definitive or fully developed. It is simply a concept employed at NASA until alternative space-station concepts are received from industry. By focusing now on architecture rather than on configuration, we hope to ensure a space station whose foundation is intellectually sound.

Nevertheless, certain characteristics of the space station are known. Whatever the final architecture, it will be Shuttle-launched and -tended. Communi-

cations will be by the Tracking and Data Relay Satellite System. At first the station may be a relatively small facility, modular in nature but expandable. F-4 shows a small facility and a later growth version. Each phase of this evolutionary system must be useful in its own right.

The space station could well be developed in concert with other nations. Under certain conditions, a cooperative space-station venture might be highly beneficial to the United States. The total system need not be manned, nor need each timed phase of the system include manned elements, but man will be an essential element of the system.

F-3 ONE POSSIBLE SPACE-STATION ARCHITECTURE



T-2 SKYLAB'S MAJOR ASSEMBLIES AND FUNCTIONS

Module	Manufacturer	Function	Habitable working volume, m^3/ft^3
Command and service	Rockwell International	Crew ascent and descent.	5.95/210
Multiple docking adapter	Martin Marietta	Docking interface, controls and display, Earth observation, and storage.	32.28/1140
Solar observatory	MSFC[a]	Solar observation, power source, and attitude control.	— —
Airlock and fixed airlock shroud	MDAC-Eastern[b]	Power control and distribution, environmental control, data center, extra-vehicular-activity hatch, and caution and warning unit.	17.66/624
Orbital workshop	MDAC-Western	Primary working and living area, laboratory, power source, and stowage.	295.23/10,426

[a]NASA Marshall Space Flight Center. [b]McDonnell Douglas Astronautics.

In response to the directive to plan a space-station program, NASA has established a Space Station Task Force reporting directly to the associate deputy administrator. Consisting of some twenty individuals, in an agency-wide effort independent of but supported by the NASA program offices, it is directed by John D. Hodge, who was one of the early Houston flight directors and more recently served as associate administrator for policy plans and program management at the Department of Transportation. The Space Station Task Force has several mainstream activities:

• *Mission analysis.* The task force has underway several small studies to analyze mission requirements. They are intended to involve the user communities early in planning. Contractor tasks include obtaining the views of the users on how best a space station could fulfill their requirements and what specific station characteristics would best support their needs. The users include the science and applications communities, the commercial world, and national-security agencies. From the analysis of mission requirements, the contractors will derive space station architecture and make preliminary estimates of program costs and schedules.

• *Program-description documents.* As a means of identifying major issues and parameters of a space station program, the task force is preparing a set of documents that will set forth NASA's preliminary views on space-station planning. Patterned after the Space Shuttle "yellow books" of 1969, these documents outline and discuss the central program elements. Several documents or books on missions, system requirements, technology options, system definition, space-station initiation and operation, and station programmatics are planned. Working groups representing each of NASA's programs and centers will contribute to these documents under the overall direction of the task force. From this activity will emerge a solid understanding of a space-station program. Together with the mission-analysis studies, these documents, periodically updated, will constitute basic reference material for follow-on systems definition and development.

• *Management structure.* The task force is reviewing institutional organization and procedures for a space station program. The relative roles of the NASA centers, of Headquarters, and of the contractors need to be carefully considered. Decisions on those roles will have to be made by the NASA administrator, for they involve the future of the agency itself. No final decisions on management structure have been made. They will evolve as the planning matures.

For planning purposes the task force assumes space-station development will begin in 1984 or 1985. This date could be advanced or slipped to ac-

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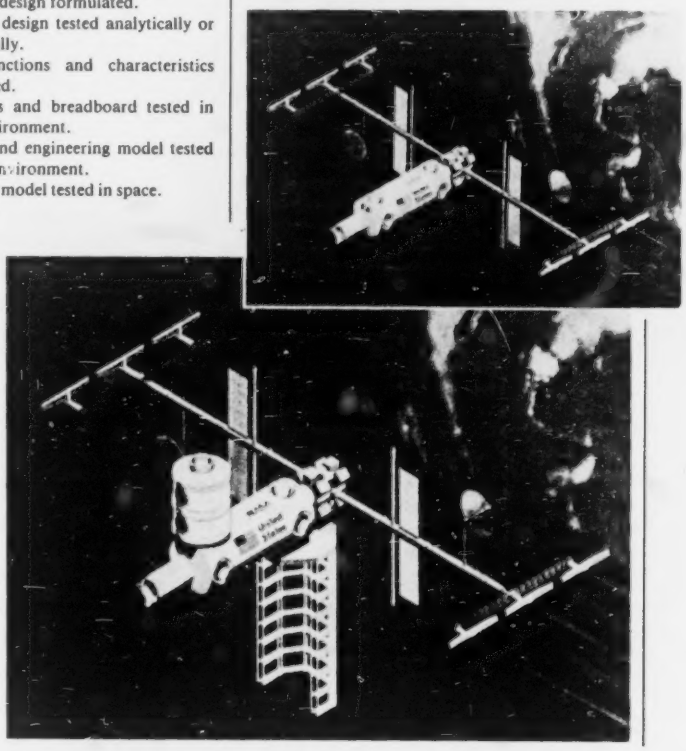
commodate the many factors and forces which influence the start of a major program. The mission-analysis studies now underway should be completed early in 1983. The program-description documents are scheduled to appear next spring. Together, this material would support space-station program definition that could begin late in 1983, assuming program approval.

In conjunction with the Space Station Task Force, NASA has established a Technology Steering Committee under the NASA Office of Aeronautics and Space Technology to assess the state of technology for a space-station program and lay out a development program that, assuming a launch by 1990, will assure technology readiness. The committee has identified the following eight levels of readiness as benchmarks for assessing space-station technologies:

Level 1 Basic principles observed and reported.
Level 2 Conceptual design formulated.
Level 3 Conceptual design tested analytically or experimentally.
Level 4 Critical functions and characteristics demonstrated.
Level 5 Components and breadboard tested in relevant environment.
Level 6 Prototype and engineering model tested in relevant environment.
Level 7 Engineering model tested in space.
Level 8 Operations.

To fulfill its mission, the Technology Steering Committee has established working groups comprised of individuals from the NASA centers and Headquarters for the following areas: data management, environmental control and life support, systems technology, attitude control and stabilization, power, thermal subsystems, propulsion, structures and mechanisms, and communications. The working groups are reviewing activities in their fields and are establishing priority tasks that would provide options for a 1984 or 1985 program start as well as options for performance improvements in a station's evolutionary growth.

As this technology effort has proceeded, the Steering Committee has realized that a number of "themes" (see T-3) cut across the various space-station technologies. They will be carefully considered in the committee's activity.



F-4 A station could begin small, as at top right, but soon evolve by adding sections, as shown below.

In addition to the work of the Space Station Task Force and the Technology Steering Committee, NASA is conducting another set of activities related to a space station. These involve the science community and are intended to ensure that science and applications requirements become an early and integral part of the planning for a space station. Through the Office of Space Science and Applications, NASA has requested a National Academy of Science (NAS) review of possible space-station utilization. Its Space Science Board spent two days this July examining how a permanent facility in low Earth orbit could serve the interests of space science. And through its Space Applications Board (SAB), the NAS later spent two weeks in August similarly examining space applications. The SAB employed ad hoc committees on Earth resources, Earth environment, ocean operations, satellite communications, and materials processing in space. The results of these two summer seminars will be used in on-going mission analyses. They also will add to the already considerable body of knowledge about the scientific potential of a space station.

The science community would be an important user of a space station. So too would the Department of Defense (DOD). Space gives to the national security communities what it gives to others: a unique vantage point from which essential activities can be conducted. A space station would carry out many such activities that otherwise might not occur. The following five national-security candidate mission areas potentially benefiting from a space station derive from a 1981 McDonnell Douglas Astronautics study entitled "Utility Analysis of a Manned Space Platform for Defense Related Missions (Task C)":

Activity	Possible program
Surveillance and reconaissance	IR telescope
Servicing and logistics	IR telescope assembly and space plane
Space command post	High-inclination mission
Data center	High-inclination mission
RDT&E	Sortie-support missions

This same study relates these mission areas to altitude and orbital inclinations (see F-5).

Given approval for a space-station program, NASA expects to develop the space station in cooperation with DOD, just as it expects to cooperate with other user communities. Such cooperation took place in the development of the Space Shuttle. The result was a vehicle of remarkable versatility and utility. We are keeping DOD advised of our space-station planning activities, and we are including defense requirements as part of the package of mission requirements to be fulfilled by a space station. For its part, DOD is participating in the mission analyses.

T-3 SPACE-STATION TECHNOLOGY "THEMES"

Themes	Components
Automation	Requirements
	Data management—
	—Architecture
	—Software and hardware
	—Data bus
	—Fault-tolerant design
	—Redundance management
	Subsystems
Human factors	Habitability—
	—Food
	—Hygiene
	—Human needs
	—Intercom
	Caution and warning
	Life Support—
	—Air
	—Water
	—Temperature and pressure
	Man-machine interaction—
	—Crew-station development
Space operations	Command and control—
	—Monitoring
	—Problem definition
	—Problem resolution
	Satellites service—
	—EVA
	—RMS
	—Teleoperation services and maintenance
	—Repair
Dynamics and control	Structural configuration and analysis design tools—
	—Dynamics
	—Thermal disturbances
	Modular growth distributed control
	Adaptive control
	Analysis and simulation—
	—Large rigid structures
	—Flexible appendages
	—Flexible structure
	Rendezvous and docking
Power and thermal-energy management	High-voltage power generation
	Power storage
	Power distribution
	Power management
	Thermal management
	Heat transport
	Heat dissipation
H_2O_2 scavenge from external tank	Cryo storage and handling
	Attitude control
	Life support
	Fuel cells
System trades	Nickel-cadmium vs. nickel-hydrogen batteries vs. fuel cells
	Closed-loop life support
	Energy storage vs. attitude control

Other participants in mission analysis are the European Space Agency (ESA) and the space agencies of Canada and Japan. They are sponsoring mission analyses of their own. Results of their studies will be shared with NASA, and NASA in turn will give them the comparable U.S. studies.

Cooperative programs with other nations are not new to NASA. Precedents for cooperation on a space-station program abound. The Space Trans-

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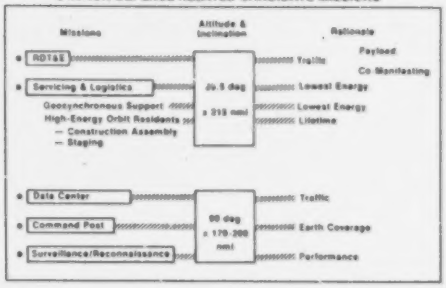
NASA Space Station Planning
(Continued from page 43)

portation System (STS), for example, includes two key elements manufactured abroad. Canada developed the Remote Manipulator System; ESA, the STS Spacelab scientific module and pallets. NASA believes that, under appropriate conditions, similar arrangements could be made for a space station.

International participation in a space-station program offers benefits to the United States. International participation could lower the cost to us. It would strengthen the link between foreign space programs and the Shuttle and to U.S. space systems in general. It also would widen the technology base of the program.

F-5 ORBITAL ALTITUDE AND INCLINATION FOR SPACE-STATION DEFENSE-RELATED CANDIDATE MISSIONS



Both James Beggs and Hans Mark have spoken positively of international participation in a space-station program. At present NASA is advising potential partners of our planning activity. Results of NASA's mission-analysis studies will be shared with them. At a later date, discussions on systems development work can be expected. These discussions will, of course, be sensitive to concerns about technology transfer and to considerations regarding the exchange of funds. They will also reflect technical and managerial factors which must be considered to assure overall system-development feasibility. It appears, however, that a space station is likely to be a system of many elements, a number of which could be suitable for development outside the U.S.

Development of the entire space-station system will clearly be a challenging technical enterprise. The challenge today will not be in any one area of space technology. There will be no space-station equivalent of the Shuttle's thermal protection system or its reusable high-pressure main engines. The challenge will be to conceive and build a space station that is properly bounded, yet can grow.

Although other NASA programs have grown and evolved before, none started with evolution so significant a major objective, nor has any other evolved in the ways we envision for the space station. Obviously, one dimension of evolution would be size; the space station undoubtedly would start small and get larger over time. Another would be technological sophistication. The station must be able to accommodate new technologies as they become available. A third dimension concerns capabilities. The space station must become more useful, efficient, and versatile with time.

Unlike previous manned spacecraft, the station must have a very long lifetime –to provide a "permanent presence" of man in space. The term does not imply forever, but rather perhaps ten or twenty years. The architecture and systems design for the space station must assume and reflect such longevity. On-orbit maintenance and system upgrading will be required, something we have provided for only to a limited extent in the past.

We have confidence, however, that NASA and its industrial partners can rise to the challenges of growth and longevity, and to other challenges that will emerge as the program progresses. America's record in space is testament to this team. Apollo, Shuttle, Viking, and Voyager were all difficult programs, successfully completed. A space station provides an opportunity to continue this tradition.

The Space Age is now entering its third decade. NASA's programs of science and applications, launch vehicles, and launch services have matured. Spacecraft orbiting Earth and exploring the solar system are commonplace. Soon, access to low Earth orbit will become routine. We are thus close to being able to take full advantage of space.

What is missing, of course, is a system that provides a permanent presence. How much more useful such a presence in space would be. Our research effort in the Antarctic is not intermittent; it is a permanent presence on the polar icecap. The first explorers of our own Western frontier created the opportunity for new uses of the land, but that opportunity was not realized until settlers—farmers and miners—arrived to stay and work.

A permanent presence, whether a base camp in the Antarctic, a settler's farm in the Northwest or Oklahoma territories, or a naval fleet in the Mediterranean, establishes a new dimension: one that reflects determination, broadens opportunity, encourages participation, stimulates new activity, and strengthens the character and vision of the people who made it happen. So too with a space station. It would remain permanently in orbit, enabling us to enjoy the full benefits of space. With the Shuttle flying, it is indeed the next logical step.

Expansion into Space

Moving from Dream to Reality

by Jerry Grey

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The United States space shuttle, much delayed but nevertheless one of the most significant technological achievements of the century, is now a reality. Its successful maiden flight, launched on April 12, 1981, was the first in six years to carry Americans into space. But what now? The shuttle, after all, is merely a truck, a means for carrying people and cargo into space; it is not an end in itself.

Originally the shuttle was a key building block in an overall space program plan that included orbiting space stations, near-weekly trips to the moon, and even a manned flight to Mars. That perhaps overambitious program fell to the budget-cutters' axe at the beginning of the 1970s, despite the world-shaking success of the Apollo program, which placed men on the moon and brought them safely back to Earth. The only surviving remnant of NASA's glorious space program was a stripped-down shuttle, its budget pared so close to the bone that many design and performance compromises were necessary and delays were inevitable.

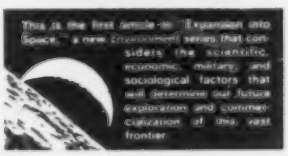
The Soviet Union, meanwhile, was quietly plodding its steady path, far less spectacularly than the Apollo program, but unerringly and unfailingly directed toward its well-defined goals. Those goals, set by the Soviet Union even before the United States formed NASA in 1958, focus on the permanent occupancy of space by Soviet cosmonauts and eventual domination of the entire cosmos by the Soviet Union.

The graceless but highly functional Salyut 6 space station, which finally plunged to Earth in July 1982 with little notice or fanfare (Salyut 7 was already in orbit by then), had been visited and occupied by dozens of cosmonauts from seven Iron Curtain nations for well over three years (1978-1981); they performed thousands of experiments aimed at learning how to utilize this vast new territory for the maximum benefit of the Soviet Union.

What will the next decade bring? Can (and should) we bridge the sizable technological and economic gap between the current generation of rudimentary space stations—Salyut, the American Skylab, and the European Spacelab—and the vast orbiting cities projected by some space visionaries? And perhaps the most important question: what would be the implications of such a move to the future of humankind?

The development of the next generation of space stations, our beachheads in space, is inevitable, not so much for the purpose of political ascendancy that motivated Apollo but for sound economic, security, scientific, and sociological reasons. The growth of these beachheads into full-scale orbiting settlements, along with solar-power satellites, the search for extraterrestrial intelligence, and eventually voyages to the stars—today hardly more than ephemeral dreams—are practical, logical and therefore also inevitable, and will totally change our perception of human existence.

In the midst of what sometimes seems to be a world falling apart around us, we stand on the brink of what could turn out to be the brightest of Earth's golden ages. This article documents not just the dreams but the reality—the knowledge and experience—on which that next great expansion is based, thereby projecting a wholly practical approach to the solution of many of today's knottiest


This is the first article in "Expansion into Space," a new Environment series that considers the scientific, economic, military, and sociological factors that will determine our future exploration and commercialization of this vast frontier.

JERRY GREY, a consulting editor for *Environment*, is the publisher of the aerospace monthly *Astronautics and Aeronautics*. He is currently vice president of the International Astronautical Federation and a consultant on space stations and international space activities to the U.S. Congress's Office of Technology Assessment. Dr. Grey was the deputy secretary for the United Nations' Second Conference on the Exploration and Peaceful Uses of Outer Space. This article is adapted, with permission, from his recent book, *Beachheads in Space: A Blueprint for the Future*, © 1983 by Macmillan, New York.

problems. One of these problems is by far the most important to us all: survival. Space is the key to its solution.

The Foundations

Long before October 4, 1957, when Sputnik 1 beeped its epoch-making way round the Earth and heralded the dawn of the Space Age, men and women were dreaming of travel beyond the Earth and planning the machines that would sustain them in the airless void.

The first concept of a true space station—a satellite orbiting the Earth with people aboard—appeared in the *Atlantic Monthly* in 1869 in a story by Edward Everett Hale called "The Brick Moon." Hale's 200-foot-diameter space station was designed to serve as a navigational aid for sailors. It included such modern features as a space-to-Earth communication system (the moon's inhabitants jumping up and down in Morse code), a resupply system (packages thrown up from Earth), an on-board life-support system (soil to grow crops that could be harvested up to 10 times a year in the cloud-free sunshine), and even such up-to-date characteristics as cost overruns.

In 1903 the famed Russian scientist Konstantin Tsiolkovsky proposed space station concepts using solar energy, artificial gravity, and closed ecological crew life-support systems. The American rocket pioneer Robert H. Goddard, in 1920, was the first to suggest that nonterrestrial materials (from the moon and asteroids) could be used to build large structures in space—a quite modern concept, considered extremely advanced even in the 1980s! Transylvanian Hermann Oberth, in 1923, built on Tsiolkovsky's and Goddard's work, predicting in his book, *Rocket into Interplanetary Space*, almost exactly what manned space platforms would be used for some 60 years later: Earth observations; bases for astronomical studies and other specific experiments; space depots for servicing, refueling, and launching other spacecraft; bases for solar space power plants; and means to evaluate human-life support systems in space. These predictions were remarkable in that Goddard had yet to fly the world's first liquid-propellant rocket (it was launched in 1926).

A Growing Interest

In 1951 Oberth's famous student, Wernher von Braun, proposed a 20-foot-diameter spinning doughnut-shaped space station. Von Braun's designs, later published in the popular press, represented the pinnacle of a quarter century of early space station conceptualization, much of which appeared between the covers of the early science-fiction "pulps." Most of the early space stations were designed to serve much the same functions as Oberth's original conception. But as experience accumulated with unmanned satellites, high-speed rocket flights, and then later with manned orbital flights, the significance of one unique aspect of spaceflight began to gain in recognition: the absence of gravity in an orbiting or free-flying satellite or space station.

There were two distinct facets to this growing interest. The first and primary one, with the idea of manned space flight in mind, was its effects on human physiology and psychology. The second, whose real importance was not recognized until considerably later in the development of spaceflight, was how this wholly new environmental feature might be used to humankind's benefit.

In considering the use of space for various purposes, one must distinguish between employing the vantage point of a platform high above the Earth—a feature used by the satellite

communications industry, weather satellites, navigation satellites, military reconnaissance satellites, astronomical and geodesic satellites, Earth resources satellites, and so on—and using the actual space *environment*; that is, the absence of gravity, the availability of an essentially infinite source of high vacuum, and the presence of undiluted, unobstructed solar energy.

The vantage-point feature was used by the very first satellites: Sputnik 1, whose beeps were heard by the entire world, making it the first "communications satellite," and Explorer 1, which discovered the van Allen radiation belts around the Earth simply because it was the first time an instrument capable of measuring them had been placed there. The space environment, however, although by now the subject of hundreds of experiments in the more recent space stations, has yet to be used for humankind's benefit.

By far the most important aspect of the space environment is what is familiarly known as zero-gravity or, more accurately *microgravity*—which means that an object in a satellite is in a condition of balance between two opposing forces: the inward gravitational pull of the Earth and the familiar outward centrifugal force due to the high speed of an object moving in a circular path. This is the same balance, of course, that keeps a hurtling satellite firmly in its orbit around the Earth.

This condition of microgravity, although its physics and mechanics have been well understood for years, presented many unknowns to those of our space pioneers, who were concerned with whether or not people could ever live and work in space or, for that matter, even survive. But as experience began to fill in the gaps in our knowledge of space flight, the shapes of spacecraft ideas underwent considerable change.

The spinning space station designs of the 1950s slowly gave way to much less complex nonspinning designs, in which crew members would experience microgravity for the full duration of their missions. The transition was accelerated by the consequences of President Kennedy's electrifying May 21, 1961, announcement setting the goal "of landing [a man] on the moon and returning him safely to Earth" by the end of the decade. Not only did it reestablish the United States' faltering prestige in the face of the Soviets' oft-demonstrated superior space capability, but it opened wide the path to ambitious planning for the next decade—the 1970s.

As the Americans and the Soviets accumulated more and more experience through the Mercury, Gemini, and Apollo programs in the United States and the Earth-orbiting Soyuz flights in the Soviet Union, the earlier bugaboos about the ability of people to live and work in space disappeared. By the time Neil Armstrong and Buzz Aldrin had fulfilled President Kennedy's promise in July 1969 by walking on the moon, with crewmate Mike Collins assisting them to guide the Appollo 11 command module to a safe splashdown in the Pacific, we had learned not only how to live and work in space for periods of up to two weeks, but also how to deal successfully with potentially disastrous emergencies, such as the explosion of an oxygen storage tank, which almost wrecked Apollo 13.

In effect, we had learned how to operate in space; now all that was needed was to find something useful to do there. That task was accomplished by both major space powers very early in the 1970s, but not before some serious soul-searching had been undertaken on both sides of the world.

Changing Moods and Missions

Late in the 1960s, as the U.S. space program was accelerating toward its sensational climax, NASA planners were busy conceptualizing their post-Apollo activities. NASA, the National Aeronautics and Space Administration, had been created by the National Aeronautics and Space Act of 1958 in response to the launching of Sputnik. Its mission, according to the law that created it, was research and the development of new space technology.

NASA's plans in pursuit of its congressionally mandated space research and development role, were ambitious: permanent space stations, starting with a 12-person design and then progressing to a 100-person behemoth; a reusable space shuttle to ferry people and cargo back and forth between the Earth's surface and the space stations; regular trips to the moon to establish and operate a permanent scientific lunar base and a lunar orbiting space station; and even a crystallization of Wernher von Braun's 1954 fantasy—a manned expedition to the planet Mars.

In the euphoria following the almost incredibly successful accomplishment of the moon landing, NASA officials proudly announced these plans to what it fully expected to be a cheering Congress and public, and promptly fell flat on their collective faces. For, despite the unquestioned success of Apollo and the unreserved national acclaim NASA received for its accomplishment, the mood of the country had changed almost imperceptibly in the last few years of the 1960s. The proposed expenditure of billions of scarce tax dollars on such esoteric and distant matters as space stations and trips to Mars for a few elite astronauts ran into a solid concrete wall, both in Congress and in an enraged American cit-

izenry. The space stations, the lunar base, and the Mars-flight dream disappeared in the political bloodbath.

But then NASA, a competent agency despite its political naiveté, came up with what later turned out to be a real winner. By early 1970, when NASA's grand plan for the future was in the process of being scuttled by public opposition, the agency cancelled its originally scheduled Apollo 20 moon flight and, instead of a full-fledged space station, announced the Skylab program, two orbiting workshops to be assembled from the leftover Apollo hardware and to be visited by seven crews over a period of two years.

Further budgetary compromises with congressional critics and the Office of Management and Budget subsequently led to an agreement to reprogram the remaining Apollo funds into a scaled-down Skylab effort consisting of only a single orbital workshop to be visited by three crews in 1973–1974. Despite the scale-down, it preserved for NASA at least a vestige of the original space station concept, which our space planners believed to be the next essential step in the conquest of space. Skylab was also needed to keep pace with the Soviets, who were even then obviously headed on a course intended to leap-frog the American moon-landing triumph by establishing a massive space station effort (see box below).

Although a makeshift substitute for even the 12-person space station NASA had originally planned, Skylab nevertheless was equipped to evaluate many of the activities that the full-fledged station had been intended to undertake. In fact, it eventually turned out to be one of the most successful and valuable space activities ever, despite the cloud of antispace feeling in which it was born.

Skylab: Shanty in Space

Skylab, the only real space station ever launched by the United States, proved unequivocally that the general-purpose computer/operator known as a human being is an in-

SOVIET ASCENDANCY

The fundamental motivation of Soviet space policy in the early years was little different than that of the United States: global prestige. The single most significant event that catapulted the Soviet Union into worldwide recognition as a major modern power and stimulated the massive American reaction was undoubtedly the launch of Sputnik 1 in 1957, backed up by the continuing string of successful unmanned and then manned space launches. From then on, it became clear that the principal strategy of the Soviet space program was to beat the Americans at every turn.

This strategy, a consequence of the basic Soviet motivation to develop global prestige as a political weapon to demonstrate the ascendancy of communism, was an outgrowth of the real Soviet military weakness at the end of World War II. At that time our big B-29s were the only aircraft capable of carrying the massive new nuclear bombs that had ended the war with Japan. Since they had no strategic air force at the end of the war, and thus no built-in airplane "constituency," the Soviets recognized the impossibility of reaching early parity with the well-established American lead.

They decided, therefore, to leapfrog the United States by developing the rocket launcher capability needed to carry their heavy nuclear bombs over intercontinental ranges. So when the International Geophysical Year rolled around in 1955, and the United States announced its intent to build (from scratch) a civil rocket and launch a scientific satellite with it, it was relatively easy for the great Russian rocket designer Sergei Korolev to convert the Soviet's existing missile launcher capability into a million-pound-thrust space launch vehicle. This big booster-rocket became the mainstay of the Soviet space program, and is still in limited use today.

According to expert Soviet-watchers, the Soviets had intended to maintain and reinforce their global image of technological superiority by beating the United States to both reaching and landing a man on the moon. They had clearly won all the preliminaries—beginning with their unmanned Luna 1, the first man-made object to reach and fly past the moon (in January 1959) and continuing through to Luna 10 (March 1966), the first spacecraft to go into orbit around the moon.

Author James Oberg (*Red Star in Orbit*) is certain that the Soviets had planned a manned launch to circle the moon in a Zond (modified Soyuz) spacecraft on December 9, 1968, two weeks before the U.S. Apollo 8 carried astronauts Borman, Lovell, and Anders around the moon. But something clearly happened at the Soviet's Tyuratam launch site, for the Soviet Union never launched its manned lunar orbiter. Never again was there even a murmur about a manned Soviet circumlunar flight. The Russians have never admitted to defeat in any arena.

Oberg has cited considerable (and convincing) evidence that the Soviets still hoped to beat the United States to the manned lunar landing. But in July 1969 the United States foiled the Soviet plan by actually fulfilling John F. Kennedy's May 1961 promise to reach the moon by the end of the decade, so again the Soviets wiped out all traces of their unsuccessful effort to win that race. From then on, they steadfastly maintained that there never had been a manned Soviet moon program.

That position might eventually have been untenable, because the whole world knew of the extensive manned Soviet activity in space, but the foreclosure of a permanent U.S. manned space station in the post-Apollo NASA massacre gave the Soviet Union the ideal opportunity: they simply said that *their* program all along had been aimed at establishing a manned presence in Earth orbit, which, besides giving them another important lead over the United States, really did have far more direct practical value than a mere prestige-building trip to the moon. And sure enough, there came another string of Soviet firsts: the first manned orbital endurance record, the world's first true space station and space-station crew, and on and on.

In the penny-pinching, post-Apollo space depression, few

dispensable element in the performance of complex, and especially emergency, tasks in space. Without the adaptability, ingenuity, and general flexibility of the human crew, there is no question that none of the Skylab mission objectives would have been achieved as a consequence of the damage the station sustained during its liftoff from Earth.

And those mission objectives were indeed important to the future of the U.S. space program, and therefore to the future economic well-being of the nation. Physiological data from Skylab astronauts established the criteria for future microgravity life-support systems, including food, exercise, recreation, personal hygiene, and physical configuration of the space craft, as well as the mechanical equipment. Skylab's medical information also defined the key physiological problems of long-term space flight—loss of calcium, muscular tissue, blood cells, etc.—which have now been solved or at least mitigated to the point at which they do not prejudice the attainment of mission objectives.

Skylab also pioneered three major lines of research in critically important areas: Earth observations, detailed studies of the Sun, and, perhaps most important, the processing of materials in a microgravity environment. Skylab taught us more about the Sun—the life-giving source of nearly all energy here on Earth—than humankind had learned in all recorded history. Those data alone were probably worth the cost of the mission; but it is as the progenitor of what will become the world's biggest 21st-century industry—manufacturing in microgravity—that will turn out to be Skylab's major contribution.

Experimenting in Space

The most important Skylab experiments were those that dealt with the growth of crystals, paving the way for major new developments in the manufacture of the semiconductor chips that are the key components in all

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noticed that the steadily plodding Soviet tortoise had again begun to outdistance the United States hare's daring leap to the moon. The Soviets were surely and steadily designing, building, and launching new, bigger, and better spacecraft. They launched Salyut 2 in April 1973, Salyut 3 in June 1974, Salyut 4 in December 1974, Salyut 5 in June 1976, Salyut 6 in September 1977, and Salyut 7 in April 1982.

This situation highlights the fundamental difference between the American and Soviet space programs. In 1958, when NASA was created, one of the basic policies written into the National Aeronautics and Space Act was that civil and military space activities were to be conducted separately. Thus the necessary secrecy that shrouds the missions, performance, and operations of all our military spacecraft is wholly absent from NASA's civil space activities. The Soviet space program does not distinguish between civil and military operations; it is *all* secret. The Soviets pick and choose only those events and data they wish to release for propaganda, prestige, or other purposes. Besides their first seven Salyut space stations, for example, at least three additional Salyut-type spacecraft were launched that were believed by our experts to have been wholly for military purposes. Further, the "nonmilitary" Salyuts, including the intensively active Salyut 6, in which the bulk of manned Soviet activity took place, unquestionably performed many military functions.

Besides the significant military presence and substantial global prestige the Soviets garnered from their highly successful orbiting space station program, they have reaped a cornucopia of economically valuable research data. Among the valuable data the Soviets have released were the results of long stays in space on cosmonauts' physiology and psychology. The other key element in Salyut's remarkable success was the Soviets' use of unmanned "freighters" to resupply the station with rocket propellants (necessary to keep Salyut's orbit from slowly decaying, as Skylab's did, and reentering the atmosphere), air, water, food, air-filter and carbon dioxide absorption cartridges, experimental materials and equipment, and the hundred and one other necessities of a four-year, wholly self-contained combination home and laboratory. These supply rockets, named Progress, were modified Soyuz (manned) spacecraft, and the combination of Soyuz, Progress, and Salyut constitutes a complete, workable, *proven* manned space system that the Soviets have said forms the core upon which they can build their expansion into space.

There is no mistaking their intent to conduct that expansion. Although the Soviets have launched many unannounced programs that they later swept under the rug for one reason or another, they have always done whatever they've announced publicly in advance, right from the first notifications of their intent to orbit Sputnik 1 (which nobody in the world listened to or believed). In June 1980, the American publication *Aviation Week & Space Technology* reported Soviet statements that a 12-person permanent space station five times larger than Salyut would be launched in the mid-1980s, using a new rocket booster bigger than the monster Saturn V that had powered the Apollo moon flights. The big space station would be employed, among other functions, to support manned flights to the moon and eventually to Mars, according to Soviet officials.

In June 1981, the Soviets docked Kosmos 1267, a big 30,000-pound spacecraft, with the dormant Salyut 6 (42,000 pounds), with the intent, according to cosmonaut Vitali Sevastyanov, of defining modular building-block techniques for the in-orbit assembly of large manned space stations. Late in 1981 even the Pentagon confirmed the fact that Russia was developing a superbooster having "six to seven times the payload capability of the space shuttle." Perhaps even more ominous, the personnel carrier needed to go along with their new giant freighter—most likely a small version of a reusable Earth-to-orbit shuttle—was tested successfully in June 1982 for operational readiness by the middle of the decade.

Whatever happens to the U.S. space program as a consequence of budgetary and political shenanigans by the administration, there is little doubt that human beings will travel further into space within the next few years. So perhaps when Senator William Proxmire (an almost legendary foe of U.S. manned space programs) caustically queries a NASA official, "Why should we spend our hard-earned money sending people out into space? What do you expect us to find there?" he might hear the response to the same question asked 20 years ago about our going to the moon: "Russians, sir; Russians!"

J. G.

computers and modern microprocessors. Other experiments dealt with the melting, refining, and joining of metals in microgravity, currently being pursued by a number of large corporations such as Deere & Company, Bethlehem Steel, U.S. Steel, and INCO. A very important class of Skylab experiments on an obscure process called electrophoresis, although not wholly successful, did lead to the first commercially viable space products—pharmaceuticals now being separated aboard current space shuttle flights for Food and Drug Administration testing before being released for sale to the public.

Skylab was the precursor to the permanent space station concepts now being examined in depth by NASA and industry, but it was far more than that. It demonstrated once and for all that mankind can move, operate, and be productive in space, and therefore opened up the riches of the entire universe for our descendants. The major tragedy is that bean-counter-mentality budget trimming, responsible for the lack of adequate orbit-raising capability, resulted in the early loss of this nation's only space station.

Compromises and Constraints

The original Skylab mission planning had called for the lowest orbit having a sufficient safety factor to prevent reentry of the laboratory before its mission was completed; the best estimates as to its reentry and eventual fall to Earth had placed it around 1983. Although NASA was well aware of the possibility that some of the larger pieces might survive their fiery descent through the atmosphere and strike the Earth, the probability of injury or death to any person here was so small that it was not worth the money to install a descent control system on the craft.

Further, by the time Skylab was launched in 1973, the space shuttle program was well under way, and its originally scheduled launch date of 1978, even if delayed, would allow Skylab to be revisited long before its projected demise so that whatever action was then considered appropriate could be taken by the shuttle's astronauts.

The expected shuttle delay did, of course, materialize, but was somewhat longer than most people expected; the first launch was not until April 1981. That could have been in time to attach a small rocket booster unit to Skylab, either to raise its orbit and save it or to direct it into a controlled and therefore predictable reentry. But one more piece of bad luck confounded the original compromise judgment: solar sunspot activity had suddenly become greater than normal during Skylab's last years, heating the Earth's atmosphere and causing it to expand. Hence, the drag on Skylab was considerably higher than had been predicted in 1973, and it was finally concluded that the United States' only space station would tumble to its demise in the summer of 1979.

Even at this late date bad luck continued to plague poor Skylab. The inadvertent reentry of a Soviet military satellite (Kosmos 954) in January 1978, spewing radioactive pieces of its nuclear power plant over much of northern Canada, raised a global outcry about the dangers of reentering spacecraft. Skylab and its accessories, at about 175,000 pounds the biggest artificial satellite by far, was an obvious target for the world's already aroused ire. NASA came under considerable criticism for its original decision not to fit Skylab with the rocket booster system that could have prevented or delayed the reentry, a decision that had been reached reluctantly, mainly as a result of budget constraints imposed by some of these very same critics.

After all the hullabaloo, in accordance with NASA's predictions, the remaining pieces of Skylab plunged into the Indian Ocean in July 1979, and a few remnants scattered themselves harmlessly over the wastelands of western Australia. The world breathed a wholly unnecessary sigh of relief, and ignored the real tragedy that resulted from shortsighted budgeting: the United States had lost its only space station. It is hoped that the next few years will see that lost capability replaced by a new, modern U.S. space station in orbit around the Earth.

The International Team

While the Soviet Salyut and the American space shuttle were stealing all the headlines at the beginning of the 1980s, a small, slender shadow was standing quietly in the wings: the European Ariane, the first large space launcher suitable for commercial use to be developed by anyone other than the two major space powers.

By 1959 the British had developed their Blue Streak missile, which was very much like the U.S. Atlas, and in September of that year De Havillands rocket engineer, Sir Geoffrey Pardoe, suggested that the Blue Streak be used as the first stage of a launch vehicle to be developed by a consortium of European nations.

After several meetings, the European Launcher Development Organization (ELDO) finally came into being in March 1962: England, France, West Germany, Australia (*not* European, but their Woomera test site was the only available satellite launch facility), Belgium, Italy, and the Netherlands. The ELDO launcher, called "Europa," was to use the Blue Streak as its first stage, the French Coralie rocket as a second stage, and the German Astris for the third stage.

Europa established a unique history in the annals of rocketry; of all its launch attempts (except for the early flights of the Blue Streak first stage alone), not a single one was successful. The final (eleventh) flight ended in an explosion that triggered a wave of defeatism among the ELDO nations, eventually leading to the demise of the organization and aggravating still further the basic differences among the leaders—France, Germany, and England.

Ariane: The Sole Legacy

But European space activity was by

no means over. During the final death throes of ELDO, its member nations, particularly France and Germany, had proposed innumerable new launch vehicle concepts and combinations. The design that eventually surfaced was basically French, with an advanced high-performance final-stage rocket developed by Germany. It was named Ariane in 1973, and became ELDO's sole, but highly significant, legacy to Europe's space future.

ELDO failed primarily because of the political problem involved in getting a dozen nations to agree not only on what programs should be attempted but also on how much each should spend and who should design and develop the necessary hardware. The heart of the controversy was in the basic European disagreement as to whether their space program should rely on U.S. capability or be independent.

One group, principally scientists, was interested mainly in pursuing space science research and exploration, and was quite willing to satisfy its spacecraft launch requirements by purchasing existing U.S. rockets or by participating in cooperative experiments aboard American or Soviet spacecraft. Another group, however, involved with practical applications such as satellite communications and remote sensing of Earth resources, was concerned that dependence on U.S. launches might raise conflict of interest problems.

Another complicating factor could be traced directly to the vagaries of United States cooperation with Europe. In 1969 the NASA administrator, then Thomas Paine, had toured the world to explore the interests of other nations in participating with the United States in its space shuttle and space station plans. The Europeans liked the idea of involvement with the far more advanced U.S. space program, but were wary of the shaky post-Apollo political situation in the United States. They sent out cautious feelers to the United States for two different European developments to interact with the U.S. space shuttle: a space laboratory and a space tug, a rocket-propelled vehicle used to transfer a spacecraft from one space orbit to another (as distinguished from a launcher, whose purpose is to launch spacecraft from the Earth's surface into orbit).

In July 1973 an agreement was finally worked out. By this time the U.S. political situation had stabilized, but budgetary commitment to the space shuttle was so spartan that the United States had been forced to eliminate, one by one, all the options for foreign cooperation originally offered by Tom Paine in 1969 except for the space laboratory and one of the shuttle's subsystems: the big re-

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Expansion into Space
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mote manipulator arm used to move spacecraft in and out of the shuttle's cavernous payload bay.

Finally, in 1975, with the coalescence of disparate interests brought about by the 1973 agreement, the Europeans were able to put all the pieces together and form the European Space Agency (ESA), and for the first time were able to forge a strong and coherent space program for its 11-nation constituency. Under the skillful leadership of its first director-general, multilingual Englishman Roy Gibson, ESA grew into a sound, solidly structured, capable agency.

All three major programs undertaken in the agreement of 1973 were completed successfully, in contrast to ELDO's unenviable earlier record. Although Ariane's first operational flight (in September 1982) did not succeed due to a pump failure, the system has more than fulfilled its proponents' wildest dreams by attracting commercial launch customers away from U.S. launch vehicles, not only international ones like Intelsat but even U.S. corporations such as General Telephone and Electric, Southern Pacific Communications, and Western Union. And the shuttle-compatible space laboratory, now respectfully known by the proper name Spacelab, is a fully developed essential component of the over-all space shuttle program.

Just What the Name Implies

While the Europeans consider Ariane the diadem in their space program crown, it is Spacelab that will undoubtedly have the most important consequences for both Europe's and the world's future. It is the first laboratory designed wholly and specifically for research in microgravity and orbital observations, with no need to compromise those basic functions because of transportation or crew life-support requirements as both Skylab and Salyut had to do. Spacelab is therefore uniquely suited to the task it was conceived for: exploring the potential microgravity and the orbital vantage point to the maximum extent possible with the technology of the 1980s.

Basically, Spacelab is just what its name implies: a laboratory for conducting experiments in space. It is the only *manned* space laboratory in the free world, although many unmanned test facilities and crew-tended experiments have been designed and built for use in the shuttle. ESA rents Spacelab's facilities to any user, whether government or commercial, at a rate that depends on the kinds of services and equipment required. The United States, incidentally, as part of the original joint agreement, has purchased the entire Number 2 Spacelab for its own use.

The key factor in Spacelab's operation is its relationship with the shuttle. It is carried into low Earth orbit in the shuttle's payload bay, and remains there for the duration of its mission. All essential services to Spacelab and its crew are provided by the shuttle: electric power, thermal control, food, air, water, sleeping quarters, data handling, communications, and all other "housekeeping" functions. The crew moves between Spacelab and the shuttle middeck via a tunnel. Both Spacelab and the shuttle's crew compartment are pressurized to a shirtsleeve environment.

But alone, Spacelab loses many of its primary capabilities. Thus, any future for European manned space activity probably depends directly on its relations with the United States and on the health of the U.S space shuttle program and its descendants.

Further Cuts and Instabilities

Unfortunately, however, a resurgence of the American space program

instability comparable to that of the post-Apollo period began to surface late in President Carter's administration and grew to serious proportions during Reagan's term. This situation created consternation among ESA's executives, who saw bits and pieces of their cooperative programs with the United States dissolving as the U.S. space budget cuts broadened and deepened around the beginning of the 1980s.

In the Reagan-Stockman budgetary massacre that sought desperately to reduce federal budget deficits, not only was Spacelab support cut further but the Europeans' worst fears were realized: the United States withdrew altogether from the International Solar Polar Mission (ISPM), next to Spacelab the largest American-European cooperative program in space.

The ISPM was originally to have consisted of two spacecraft, one American and one European, launched toward Jupiter by a single U.S space shuttle in 1983. Each would use Jupiter's gravity to swing itself way out of the ecliptic plane (in which all the planets of the solar system revolve around the sun) and head back to the sun, where they would explore both poles of the sun simultaneously. Each spacecraft was to carry different but complementary instruments; the combination would constitute a complete, integrated experiment whose results were expected to increase significantly our knowledge and understanding of the sun.

ISPM's first hurdle, after approval by both NASA and ESA and their respective legislative bodies, was a two-year delay caused by U.S. space program budget constraints; ESA was forced to swallow a consequent $20 million cost increase. In 1980 the United States further complicated the issue by changing the upper-stage rocket vehicle that was to carry the two spacecrafts to Jupiter, and budgetary pressure almost deleted the whole program from the U.S. budget. In February 1981 the axe finally fell: NASA advised ESA, without prior consultation, that the U.S. spacecraft would be deleted from the program.

ESA was understandably enraged. Seventeen European institutes found their experiments abruptly cancelled; $100 million, half the total mission cost, in all-too-scarce European research funds had already been spent; and the United States had, in effect, reneged on a contract commitment. The United States' unilateral ISPM cancellation and cut-backs in shuttle/Spacelab integration were clear evidence to the Europeans that their early insistence on space independence was justified, and that their decisions to move ahead with their Ariane launcher and their own satellite programs, expensive as they were, had been well founded.

Manned space activities in the 1980s, therefore, undoubtedly would have been dominated totally by the Soviets if not for the Europeans. Although the European space program is still closely tied to that of the United States, for budgetary and political reasons as well as those long-term commitments that still exist, their Spacelab, used with the shuttle, is the only game in the free world's town, at least as far as civil-oriented manned space experiments go.

Orbital War Games

But the civil space program, important as it is, forms only part of the total space picture. By 1982, the Reagan administration's strong defense orientation, as well as the real long-term needs of the Department of Defense, had finally aroused public recognition of the growing role of the military in space planning. The Soviets, right from the beginning of their space program, have devoted the bulk of their attention to military considerations; it wasn't until 1981, however, that U.S. military space spending equaled (and subsequently exceeded) NASA's civil space budgets.

It is unfortunate but nevertheless a fact of life on Earth today that much of our expansion into space, and the beachheads that make that expansion possible, will be motivated not by the drive for humankind to develop and to grow but rather by our need to protect ourselves against one another. Military security dominates space development on both sides of the world. The next series of Soviet beachheads, like their last, will serve primarily military functions. There's at least a good chance that America's will, too.

Lofty Intentions and Treaties

In the United States, the National Aeronautics and Space Act of 1958, which created NASA, was careful to separate the military from the civil aspects of space activities, and also specified international cooperation, an eminently nonmilitary function, as one of NASA's primary directives. In the Soviet Union, no distinction is made between military and civil space activities, but there has always been far more than just a token effort in the nonmilitary arena, including extensive cooperation with the United States and other nations in scientific space projects.

The real drive toward minimizing the military aspects of space, however, came from the international political and scientific organizations. There were strong reasons for seeking a peaceful motivation in such matters as a global communications network, the rescue of astronauts or cosmonauts in the event of a mishap, or satellites that flew heedlessly, due to the exigencies of orbital mechanics, over national boundaries, indiscriminately photographing what lay open beneath them.

The United Nations' instrumentality set up to deal with space was designated the Committee on the Peaceful Uses of Outer Space. The principal accomplishment of that committee was the drafting and signing (by more than 100 nations, including the Soviet Union) of a Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, popularly known as the Outer Space Treaty of 1967.

But despite these lofty intentions, the high ground of space has been simply too irresistible to military strategists. This steady growth in the

use of space for military purposes on both sides of the world has been justifiably noted with alarm by many nations, especially by the Third World countries, who do not want to get caught in an East-West conflict waged from above. At the same time, however, it is important that even the most vociferous critics of this development acknowledge both the reality and the complexity of the matter: specifically, that militarization of space *does* exist and that it can mean *many* things, some good, some bad.

Military satellites have orbited the Earth almost from the beginning of the Space Age. All present military satellites are passive—they observe, record, and transmit electronic messages, but they do not attack, destroy, or damage anything. Aside from the classic military functions of reconnaissance, surveillance, communications, navigation, weather prediction, target acquisition and tracking, and, to a limited degree, control of other vehicles, the present complement of military surveillance satellites is instrumental in monitoring treaties and arms limitations agreements of the adversarial nations. Without that capability there can be no verification of compliance, and therefore no effective arms control agreements.

Hence, indiscriminate, across-the-board opposition to militarization of space is not only impractical but also fails to recognize that, although militarily motivated systems may not have been conceived and deployed for the most humanitarian of reasons, they certainly contribute substantially to global peace and prosperity. Nevertheless, there still remain the specters of sudden, unseen death raining down from the blackness of space and of Star Wars-like lasers zapping peaceful satellites and vulnerable manned space stations. The major space powers, despite the obvious intent of the 1967 Outer Space Treaty, are moving inexorably toward the development of a capability for warfare in space.

New Missions, New Weapons

Early steps in that direction were taken by both the United States and the Soviet Union. In the 1960s the U.S. Air Force had proposed a number of manned spacecraft dedicated to military use: a manned orbital laboratory (which later formed much of the basis for Skylab); a rocket-launched Dyna-Soar spaceplane, whose technology was crucial for space shuttle development; a full-fledged Aerospaceplane, which was to take off and land like an airplane but was capable of orbital flight in space; and several others. The Soviets had spent considerable effort developing a Fractional-Orbit Ballistic System, which was, in effect, an orbiting bomb.

But these early space weapons were not oriented toward battle with other spacecraft à la Star Wars; they were intended to perform much the same function as the intercontinental ballistic missile or the manned bomber aircraft: the destruction of ground targets. As the ICBM and particularly the SLBM—the Submarine-Launched Ballistic Missile—became more and more sophisticated and effective, these programs to develop space-based alternatives that performed the same kind of mission became less and less attractive and, one by one, were terminated or cancelled.

But in the late 1970s developments were begun by both the United States and the Soviet Union on a new generation of space weapons oriented toward a wholly different class of missions: the destruction in space of "unfriendly" spacecraft or missiles. By moving the arena of conflict from the ground into space, these new weapons reopened the subject that had supposedly been closed by the

1967 Outer Space Treaty: the use of weapons in outer space.

The treaty specifically states (Article IV) that "the establishment of military bases, installations and fortifications, *the testing of any types of weapons* and *the conduct of military maneuvers* on celestial bodies shall be forbidden" (emphasis added). The space lawyers argue whether that clause is intended to include space, as well as the celestial bodies, since the full title of the treaty is Treaty on Principles Governing the Activities of States in the Exploration and Use of *Outer Space*, Including the Moon and other Celestial Bodies (emphasis added).

The same Article IV also stipulates that "states parties to the Treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, *or station such weapons in outer space in any other manner*" (emphasis added). The lawyers also argue about the definition of mass destruction. Hence there does remain a question—a space law loophole—as to whether the use of a *non*-nuclear weapon in the depths of space is forbidden by the treaty.

The "Sanctuary" Dilemma

But whether or not such a loophole does exist, both the United States and the Soviet Union have undertaken the development of antisatellite weapons, much to the chagrin of those who are concerned that space, as the most international arena, be reserved only for peaceful purposes. The growing importance of passive military spacecraft to the overall defense forces of the major powers means that they are prime military targets. Since the first job for any responsible field commander in the event of an outbreak in hostilities is to destroy the enemy's observation, command, and communication posts, which today means satellites, antisatellite weapons can be viewed simply as an extension of the bow and arrow, the catapult, the naval gun, the bomber airplane, and the air-to-air missile, all accepted as "standard" weapons.

Although antisatellites are generally considered bad by most people, there are arguments that antisatellites are neither categorically good nor categorically bad. Dr. Eberhardt Rechtin, president of the Aerospace Corporation, has said that it depends on the uses of the device. "For example," he notes,

> *if one's objective is to protect lines of communication between the United States and NATO Europe, and if Soviet satellites are being used to target weapons onto our ships, then one would view shooting down Soviet satellites with antisatellite weapons much as one would view shooting down Soviet reconnaissance aircraft with missiles.*

And he further argues against the overall "space sanctuary" concept—that all space should be off limits to military action—by claiming that

> *putting such satellites into sanctuary would seem as strange as putting Soviet reconnaissance aircraft into a prohibited target status . . . particularly when we note that the U.S. antisatellite weapon is essentially an air-to-air missile where the target happens to be at somewhat higher altitude.*

On the other hand, space is a unique region in that it is both by law and by its very nature unadorned with national boundaries. It is clearly desirable, therefore, to maintain it as some sort of nonmilitary sanctuary, as was the intent of the 1967 treaty ratified by most of the world's nations. Resolution of this dilemma—maintaining space inviolate to weapons of any kind while simultaneously depending on space for essential support of "acceptable" military operations (including treaty

compliance)—is the major question for consideration by all nations.

Directed-Energy Weapons

At the same time that the acceptability of antisatellite development is being debated in the international arena, there are indications that a movement toward exporting to space terrestrial militarism in the worst sense is already under way: the wholesale use of directed-energy weapons. Both the United States and the Soviet Union are heavily committed to research and development leading to the deployment of weapons employing lasers, beams of high-energy charged particles (protons or electrons), and beams of high-velocity neutral atoms, all of which are far more practical in the vacuum of space than they are in the atmosphere, and any of which would have obvious military applications in space. Although it can be argued on physical grounds that such devices are not "weapons of mass destruction," which are forbidden by the 1967 Outer Space Treaty, they could nevertheless lead to the rapid escalation of our terrestrial wars into space, an eventuality that is deeply and philosophically disturbing to most of the world's peoples.

Perhaps even more significant than this philosophical concern is the very practical one that a weapon capable of nullifying a preemptive strike by intercontinental or submarine-launched ballistic missiles, as the antimissile space-based laser battle station may turn out to be, would seriously destabilize the balance of terror called "mutual assured destruction," which has, at least to date, kept the major nuclear powers from destroying the world. Thus, directed-energy space weapons could turn out to be as significant a political influence as the ICBM or even nuclear weapons themselves.

Of the three types of directed-energy weapons, lasers are by far the most likely to emerge as an operationally practical weapon system. By the mid-1960s, the Soviets were intensively investigating the prospects for laser weapons—beams of high-intensity radiation capable of cutting through inches of steel in seconds at distances measured in thousands of miles. By 1982 the United States was committing $300 million annually to high-energy laser research and development; the Soviets an estimated four times as much. U.S. representatives and senators, led by Senator Malcolm Wallop (R.-Wyo.), successfully bullied the Department of Defense into making a commitment not merely to laser research and development but to a full-fledged anti-ICBM system of 18 laser-armed satellites by mid-1990, at a cost estimated to be from tens to hundreds of billions of dollars.

If such space weaponry is eventually deployed, despite vociferous global objections, people will probably still be needed to service and guide them, just as with Earth-based weapons. This possibility brings us back to the more general questions: what beachheads will be needed in space to conduct our future orbital operations? How will they be developed from what we know and have already built today? And how soon?

Building the Beachheads

The immediate and urgent problems of the 1980s of constrained capital and high interest rates, of urban decay and soaring health and welfare costs, have made it difficult for governments to invest in the development of relatively long-term, even though beneficial, enterprises such as space technology, except perhaps for sacrosanct national security matters. For these reasons, the development of our next generation of space beachheads is proceeding cautiously, with cancellations and stretchouts and public breast-beating by both proponents and opponents of space exploration in the federal and private sectors.

But cautious as it may be, development is proceeding. In the late 1970s, it was almost wholly Soviet, European, and Japanese—while the United States was deciding on the fate of the delayed and costly space shuttle. Now that the shuttle is operational, however, the United States has moved—cautiously, to be sure, due to the Reagan administration's efforts to reduce all nonmandated and nonmilitary federal budgets—toward the next step in space: planning for the development of a truly operational orbital capability to service the growing space industry, to perform the scientific and technical research needed to sustain it, and to provide the national security functions that can be fulfilled better by people than by robot spacecraft.

The Space Platform Concept

The underpinnings of that movement were laid in the mid-1970s with conceptual designs of space stations built on Skylab experience, with robot and teleoperator system designs, with unmanned, multipurpose orbital platforms for communications and scientific experiments, with large space-based power plants capable of servicing the orbital stations, and with the space transportation concepts necessary for their logistic support. Aimed at supplementing the limited-time capability of Spacelab, which requires the services of short-term space-shuttle power supplies and other houskeeping essentials, these so-called space platforms were conceived to support orbital activities for months at a time. Designed to be serviced by the space shuttle, the space platforms would have provided utilities, stability in orbit, and access to their payloads for maintenance, repair, and replacement.

The first such platforms, called "science and applications space platforms" (SASP), were to have been located in low Earth orbit, convenient to access by the space shuttle's crew. Platforms would be fitted with sufficient propulsion capability both to maintain their orbital attitude stability and to "reboost" them upon decay of their orbits due to drag, so that the Skylab debacle need never occur again. These propulsors would be refueled by shuttle crews as necessary, along with their performance of other routine maintenance tasks.

The next step was to have been to equip these unmanned low-orbit platforms with a minimal capability for manned occupancy. One approach is to hook up to the unmanned platform a modified Spacelab, thereby converting it into what NASA called a "science and applications manned space platform" (SAMSP). It would be manned only while the shuttle is hooked up to it, but unlike Spacelab, its experiments and other equipment would continue to operate in orbit after the shuttle's departure. Following that, a support subsystem module, also derived from Spacelab, capable of supporting a crew of four for several months, might be added. In this way, SAMSP and its ilk would have been, in concept, true beachheads—small emplacements on the shores of space around which would grow the larger logistic bases and ultimately the permanent stations and settlements that will lead to the expansion of humankind into the universe. The present U.S. space station program, under which NASA hopes to place its first manned station in orbit early in the 1990s, is the successor to SASP and SAMSP.

Powering the Crafts

The key to growth in space, as on Earth, is energy. But the fossil fuels that provide the bulk of power on Earth are not suitable for use in space. Their energy content per pound is simply too low to be practical on a large scale there, since every pound of material used in space, at least for the next decade or two, must be launched from the surface of the Earth by rockets at costs, even with the new space shuttle, of about $1000 per pound. Aside from limited propulsion needs and short-term requirements, therefore, power in space must be generated either from solar radiation or from nuclear fuels.

Most spacecraft in use today derive their power from solar energy, which is available in space unobstructed by the vagaries of Earth's weather. The device used to convert solar radiation to electricity is the photovoltaic converter, commonly called the solar cell. The arrays of solar cells used on Skylab constituted the highest power photovoltaic system ever flown in space up to that time. Larger panels have been under development ever since, employing much more efficient and durable solar cells and electrical auxiliary equipment. Although military requirements for extremely low mass are currently driving the state of the art in photovoltaic technology, the more or less standard silicon-cell systems have achieved a high level of performance and reliability.

Panels built by Lockheed using silicon cells manufactured by the Applied Solar Energy Corporation are capable of generating 25 kilowatts continuously, developing a peak power nearly three times that level to allow for charging batteries and for the slow deterioration of the cells due to cosmic radiation damage. These panels were originally developed as the power source for an electric rocket, called the Solar-Electric Propulsion Stage (SEPS), needed for high-energy missions to such elusive scientific targets as Halley's comet. But when the Halley's comet mission disappeared into the maw of Reagan's budget-cutting juggernaut in 1981, the almost fully developed SEPS solar power supply was adapted to a power extension package (PEP) for the space shuttle.

Such a package would allow the orbiter to remain in space for up to a month instead of only the week permitted by its chemically powered fuel cells. But because PEP was to be carried up and down in the shuttle, it didn't leave room for the kind of payloads it was best suited to service: Spacelab, for example.

PEP therefore evolved into a slightly larger power module (PM), which could extend Spacelab's staying time in orbit to two months. The power module would be carried into orbit by one space shuttle flight (along with other payloads), and would be set up, turned on, and checked out by the shuttle crew. It would be left there, soaking up solar energy to charge its batteries, while the shuttle orbiter returned to Earth for its next load. A Spacelab module equipped for habitation would then be brought up by a shuttle, would be hooked up to the power module, and would remain for one or two months. Another shuttle would then retrieve the Spacelab, bringing it back to Earth for crew and expendables replacement and evaluation of its films and data.

But Spacelabs also turned out to be budget-limited in number, so the *unmanned* space platform concept was finally born, employing the selfsame photovoltaic array design used for SEPS, PEP, and the power module. Then, should manned servicing be required, the platform could grow into a SAMSP or one of the other human-serviced systems described previously.

But to take full advantage of the available opportunities, we still need to learn how to build large structures in space. Big antennas, large solar panels to provide multiples of the power module's 25 kilowatts, and structural "buses" for multipurpose communications satellites cannot be carried up in one piece by the space shuttle. Materials and structures needed for the big, higher-orbit commercial communications satellites require some sort of "space tug" to transport them from the low Earth orbits accessible to the space shuttle up to the much higher orbits needed for such satellites.

There are many possible approaches to satisfying that need. The most comprehensive and yet perhaps the most practical of these, which would be capable not only of supporting the construction of large systems but also of satisfying most of the scientific, logistic, and on-orbit servicing needs of both government and industry, was the Space Operations Center (SOC).

The Space Operations Center

SOC was originally conceived as a possible follow-up to the unmanned space platform and its derivative, SAMSP. But in the early 1980s NASA desperately needed a highly

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visible manned space goal to replace the space shuttle as its "big project." SOC, which would circle the Earth in a low orbit readily accessible by the shuttle, was seen by its planners at NASA primarily as supporting space construction development, some military missions, and in-orbit research and commercial operations, a principal goal being the servicing of higher-orbit satellites with the aid of a space-based tug.

Although the Space Operations Center is no longer being considered as NASA's initial space station program, for the reasons stated earlier, it was the most sophisticated, imaginative, and comprehensive concept examined, and therefore is worthy of consideration as a sample of what might eventually be developed. As originally designed, SOC consisted of two slender cylindrical service modules bolted end to end, forming the spine of the space station. Attached to one side of each service module was a larger-diameter cylindrical habitation module, housing four crew members. A safety tunnel connected the outer ends of the two habitation modules. On the other side of the service modules were a logistics (supply) module and two big rectangular space-tug hangars, suitable for assembling spacecraft and their propulsion stages for outbound trips and for refueling and servicing the station's two tugs.

A construction module, fitted with remote manipulator arms and a heavy-duty cherrypicker crane, was mounted alongside one of the habitation modules. A long boom perpendicular to the main plane of the station carried two big solar panels, the radiators for dissipating the station's waste heat into space, and antennas for communicating with the Earth and with other spacecraft. A number of airlocks and space shuttle docking ports were distributed in various places on the station.

Even before the SOC concept had been discarded, though (1981–1982), it became clear that the low-budget environment imposed by the Reagan administration would not support a full-fledged development program, with a peak-year funding requirement of $900 million (1980 dollars) in 1989, which by then would nearly double as a result of inflation. NASA therefore came up with a stretched-out program, at considerably higher overall cost but with a peak-year funding requirement leveling out at about $650 million (1980 dollars) from 1988 to 1992. It also ended up with a somewhat greater capability than the original design. Here's how it was envisioned:

First, only the two service modules would be launched, along with the solar panels, logistics module, and other necessaries. Each service module would be jury-rigged to sleep and support two crew members. (Alternative starting-points could be an automated (unmanned) platform or a minimum station having only one service module equipped for a crew of two or three.) This initial configuration could develop in one of two ways. One was to add first one four-person habitation module, then eventually a second, and then the other SOC features (hangars, construction modules, etc.).

The other path would add shorter habitation modules, each capable of sustaining only two people, ultimately reaching a total of four modules. Small modules such as these are more suitable for high-inclination (near-polar) or high-altitude (geostationary) orbits, and could therefore serve as the basic design for a second SOC. Both these options end up with a total of twelve crew members, as compared with the original SOC design's complement of eight. (Boeing had projected a need for as many as fifty people in space to service the needs of U.S. space operations by the end of the century.)

Options and Opportunities

Others besides NASA and the Department of Defense see the eventual need for a space station. Many designs have been put forward, some even larger and more elaborate than NASA's relatively sophisticated SOC; others are smaller and more constrained. In all these schemes, greater attention is given to the habitability requirements of their human occupants, including both

physiological and psychological factors, than was the case with Skylab, Salyut, and the shuttle—in which human comfort was subsidiary to functional systems and hardware. Studies have identified a whole gamut of stress-inducing factors based on the data available from Skylab flights and also on the experiences of people who have been confined on Earth for long periods in similarly isolated and stressful environments.

The Soviet crews were taught how to counteract these stress-inducing factors through biofeedback and techniques for conversation, activities, and group interactions specifically designed to reduce stress. Such methods are extremely important to the success of long-term space habitation; perhaps the motivation underlying the Soviets' careful attention to them is their well-established long-term goal of dominating orbital space. Although they terminated Salyut 6 manned operations at the end of 1980 for a period lasting well over a year, this hiatus was merely a time for retrenchment and preparation for the next major phase of manned Soviet space activity.

By April 1982 the Soviets had launched their next manned space station, Salyut 7. It is their often reiterated plan to launch the new class of 12-person stations that they had announced in mid-1980, carried into orbit by their big new booster. The military superiority that station might bring them can only be imagined, but its economic benefits have been well advertised. Whether or not the United States proceeds with its space station, no one need doubt that the Russians will proceed with theirs, and the real prospects for major industrial returns for space in the next decade will bring the Europeans and the Japanese right on their heels.

Is the United States about to relive the industrial debacles of its automobile, steel, and electronic industries, and now even its once unequaled aircraft industry? America is still desperately hanging on as one of the world leaders in space, but, with present federal policies entrenched, it won't be long before that industry too will fall behind as the others did before it.

The Next Logical Extension

The "space policies" issued by Presidents Carter (in 1978) and Reagan (in 1982) were insipid "business as usual" programs that wholly ignored the urgent need for U.S. economic survival in the now global technological arena of aeronautics and space industries. Both policies leaned heavily toward the military activities outlined earlier in this article: it is not generally known that by 1982 the U.S. military space budget had exceeded that of NASA.

The consequences of these nearsighted, lackluster federal space policies were obviously well recognized by some congressmen as well as by a number of individuals and organizations. Principal among these were representatives of the growing space constituency, not only well-established professional societies but also relatively new and publicly vociferous groups such as the L-5 Society and a whole host of space-oriented political action committees and pressure groups.

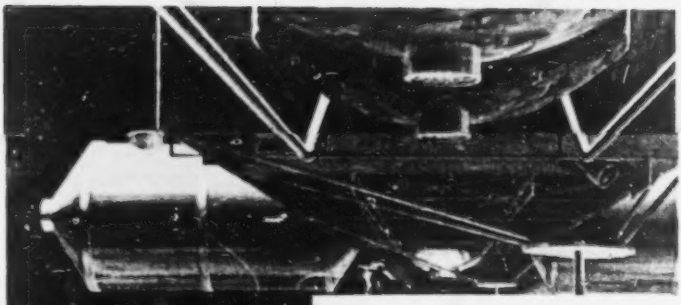
Many of these organizations formulated space policy statements intended to fill the gap left by the Reagan administration in 1981 and 1982. The centerpiece of these policies, almost uniformly, was recognition of the need for permanent U.S. orbital beachheads, significantly more capable than the Soviet Salyuts 6 and 7, as focal points to support future space activities of all kinds—communications, Earth observations (including surveillance and reconnaissance), space industry, science, exploration, building future space capability, and national security functions such as command, control, and intelligence.

It was clearly recognized by these groups that, without orbital support capability, none of the perceived benefits of space industry could be realized effectively. As will be discussed in greater detail in subsequent articles in *Environment's* series, "Expansion into Space," the advanced communications platforms that could satisfy the burgeoning needs of the developing nations without geostationary-orbit saturation, leading to the "one world" of international visionaries; fulfillment of the growing global demand for nondepletable, pollution-free energy; dispelling forever the concept that the human race need be constrained by limits to growth imposed by the planet of its birth and infancy; placing the human race in the position of equals rather than inferiors in the eventual inevitable confrontation with other extraterrestrial civilizations—all these goals depend on the availability of human and material resources in orbital space around our Earth.

Our beachheads in space, like the space shuttle, are not ends in themselves. The embryo space stations we have already launched, and the bigger and more capable ones that will follow in the coming decades, are what will make possible the continued growth of humanity. Expansion into space is the next logical extension of our past movements on land, over the seas, and into the atmosphere of our home planet. And as with all growing organisms, that expansion is inevitable.

Let's just be sure we do it right.

Photos courtesy of NASA



By WALTER B. OLSTAD
NASA Associate Administrator
for Management

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Targeting Space Station Technologies

The options must be ready by 1986 and longer-range candidates must mesh with the evolutionary plan for a permanent space base

The next logical major step in this nation's space program has long been considered to be a permanent, manned Earth-orbiting space station, as discussed by Philip Culbertson in the September 1982 *AIA* (page 36). Our nation cannot afford to forego this step. Not only has the Soviet Union been using a small space station regularly, the Salyut, it has announced its intent to establish a permanent manned base in near-Earth orbit. Other developed nations of Europe, Canada, and Japan have shown serious interest in undertaking joint ventures with the U.S. or unilaterally if need be.

Development of technology for the proposed U.S. space station, as with any major high-technology project, must begin well before the establishment of its system requirements. The technologist must anticipate requirements. A space station comparable to Salyuts 6 and 7 could be built with Skylab-level technology, but this would not be desirable because the U.S. model would not become operational for nearly a decade. Moreover, use of available technology would not allow much poten-

tial for growth, enable cost-effective extension of station life through on-orbit maintenance, or insure affordable operational costs. Indeed a Space Station Technology Steering Committee (SSTSC) established by NASA (see box on page 30), has concluded that *now* rather than later, we should be innovative and take risks in aiming advanced and unproven technology at the space-station design goal.

The SSTSC has set the following objectives:

- Establish the desired level of technology to be used in the initial design and operation of an evolutionary, long-life space station and the longer-term technology to improve capabilities. (Initial technology should be available by about 1986 to support a space-station launch as early as 1990.)
- Assess the level of technology forecast to be available from the current R&T base.
- Plan, recommend, and monitor a program to move the current technology to the level stated in the first bulleted paragraph above.
- Identify, evaluate, and recommend opportunities to use the space station as an R&T facility.

Development of a permanent manned space station has continuously been the subject of consideration since the beginning of the space age. In 1952 *Colliers* magazine described a space-station concept advanced by a group of space pioneers including Wernher von Braun, Joseph Kaplan, Frederick Whipple, Heinz Haber, and Willy Ley. The opening of space flight spurred numerous station studies, activities, and several experimental stations:

1952	*Colliers* magazine article "Man Will Conquer Space Soon" (von Braun, Kaplan, Whipple, Haber, Ley, et al).
1958	*London Daily Mail* "Home in Space" space-station design contest won by Douglas Aircraft.
1959	Military Test Space Station studies conducted.
1960	IAS/NASA/Rand Corp. Manned Space Stations Symposium.
1963	Langley Research Center establishes an office to study the Manned Orbiting Research Laboratory.
1964	DOD initiates Manned Orbiting Laboratory studies.
1967	Planning begins for post-Apollo space station later known as Skylab.
1971	Salyut I launched April 19.
1973-76	Salyuts 2-5 launched April 1973, June 1974, June 1976.
1973	Skylab launched May 14.
1975	Manned Orbital Systems Concepts study of Spacelab-derived configuration.
1977	Salyut 6 launched in September.
1979	Space Operations Center study undertaken.
1979	Science and Applications Space Platform study undertaken.
1982	Salyut 7 launched in April.

WALTER B. OLSTAD (M), associate administrator for management, chairs NASA's Space Station Technology Steering Committee. He came to Headquarters in 1979 from NASA-Langley where he had served as chief of the Space Systems Division.

Several trends have emerged. All of the early designs proposed rotation of all or part of the station to provide an artificial-gravity environment for the crew. Actual flight experience indicated that a well-conditioned crew can stand a zero-g environment for at least 180 days. Some risk of space sickness remains (usually restricted to the first several days of zero-g exposure) and some difficulty in reacclimation upon return to the ground. We still do not know the long-term effects of zero-g, but the regularity of Shuttle flights removes this as a practical concern in the near term for an Earth-orbital station.

Many early space-station concepts assumed nuclear power systems. Lack of sufficient technical progress caused this option to be dropped. Meanwhile, the solar-cell power system became the leading candidate, surpassing both nuclear and solar-collector heat-engine systems.

Another trend in U.S. studies has concerned extravehicular activities (EVA). Some designers concluded it should be used only for contingencies, minor construction work, and limited payload handling—despite the important role of EVA in the Skylab and Salyut programs and its dramatic extensive use in the Apollo program. A change from the 5-psi oxygen-rich atmosphere of Skylab and Apollo to the 14.7-psi atmosphere of Shuttle complicates EVA by requiring extensive periods of prebreathing or development of a higher-pressure EVA suit. The reservations of some notwithstanding, EVA will become, we believe, part of routine space-station operations to gain flexibility and lower costs.

Use of residual payload capacity for in-situ test and checkout of space station subsystems while still under development can reduce the need for elaborate and expensive ground facilities and verification programs. Later, during station operation, use of residual payload capacity for resupply also will help reduce costs. Being chiefly a logistics vehicle, the Shuttle will not remain with the space station. It cannot be counted on for immediate evacuation in the event of an emergency. Other means to assure

SPACE STATION AND SPACE STATION TECHNOLOGY STEERING COMMITTEES

To plan and coordinate a space-station program, NASA has established an agency-wide management structure independent of, but supported by, its program offices and centers. A Space Station Steering Committee chaired by Philip E. Culbertson, NASA associate deputy administrator, leads this effort. The steering committee consists of the NASA associate administrators, the director of the Space Station Task Force, and the chairman of the Space Station Technology Steering Committee (SSTSC).

The task force, under John D. Hodge, directs analysis of mission requirements, development of a set of program-description documents, and review of institutional organization and procedures for a space-station program.

The SSTSC, chaired by me, covers technologies in the spectrum from basic research to project development. Its members are listed below.

In addition to the work of the task force and the SSTSC, the steering committee coordinates science and applications requirements to assure that they become an early and integral part of the space-station planning. The National Academy of Science convened its Space Science Board and its Space Applications Board this past summer to study potential use of a space station. The results help guide inputs to contracted mission-analysis studies. The steering committee also coordinates cooperative and complementary activities with the DOD, the European Space Agency, and the space agencies of Canada and Japan.

Walter B. Olstad, chairman
NASA Associate Administrator for Management

Dell P. Williams, deputy chairman
Director, Space Systems Div.
NASA Office of Aeronautics and Space Technology (OAST)

Richard F. Carlisle, executive sec.
Manager, Space Station Systems Office, NASA-OAST

Carolyn Kimball, executive assistant
Program Support Specialist
Space Systems Div.
NASA-OAST

Lee B. Holcomb
Manager, Computer Science & Electronics Office
NASA-OAST

Thomas F. Cochran
Space Station Task Force
NASA

William P. Bishop
Deputy Director, Life Sciences Div.
NASA Office of Space Science and Applications

Romo V. Cortez
NASA Manager, Real Time Support Computing

Paul F. Holloway
Director, Office for Space
NASA Langley Research Center

Henry H. Plotkin
Assistant Director for Program Planning
NASA Goddard Space Flight Center

Robert H. Gray
Manager, Advanced Planning and Technology Office
NASA Kennedy Space Center

Allen J. Louviere
Office of Engineering and Development
NASA Johnson Space Center

Henry O. Stone
Director, Space Technology
NASA Lewis Research Center

Luther E. Powell
Manager, Space Station Project Office
NASA Marshall Space Flight Center

Kenneth C. Coon
Manager, Technology Program
Jet Propulsion Laboratory

Joseph C. Sharp
Deputy Director, Office of Life Sciences
NASA Ames Research Center

crew safety are under study.

Advances in a number of technologies create a richer store of design possibilities than ever before. Modern electronics especially offer major improvements in autonomy, reliability, flexibility, and cost. Likewise, we have a fresh outlook on the role of people in space. Skylab demonstrated that man can play a useful role. New technology in a space station for the 1990s surely can amplify his usefulness, particularly when armed with the resources of the new electronics.

The Soviets, it should be noted, talk openly of their plans for a large, permanent manned space station targeted for 1985. It would require a booster more powerful than any previously developed by the USSR. The first test launch of this booster may come this year. The Soviets, moreover, have indicated that they are working on a shuttle vehicle to be available in 1987. A 1/20-scale model was test flown last year.

In view of these trends, among others, the SSTSC proposed a list of possible space-station requirements to give guidance to technology development. Frequently reviewed and changed, the list now reads as follows:

- A manned system in low Earth orbit.
- Shuttle-compatible for delivery, assembly, and disassembly.
- Shuttle supported, initially on 90-day cycles.
- Modular and evolutionary design to permit growth and accept new technology.
- Goal of indefinite life through on-orbit maintenance, repair, or replacement.
- Support scientific, commercial, and military uses including on-orbit satellite servicing.
- User-oriented to the extent possible.
- Life-cycle cost to be a design driver.
- Final design phase during 1987 to support first flight as early as 1991.

Items in the list still have not become very specific. For example, although calling for a crew, it does not stipulate crew size and qualifications, typi-

cal and maximum stay times, work cycles, EVA requirements, etc.

The list of requirements implies a much larger number of design options and constraints. Operation of the station in low orbit, whatever the inclination, implies propulsion for drag make-up either integral to the station or through the aid of the Shuttle; an understanding of an acceptable level of protection from radiation, space charging, and self-induced contamination; and a need to accommodate thermal cycling, communications through ground or satellite relays, and energy storage if the power-generation system depends on the Sun.

Use of the Shuttle imposes obvious limitations on module size and schemes for deployment, erection, and assembly. On the other hand, it should permit economical resupply of the space station as an adjunct to its regular missions.

Two of the more challenging requirements concern modular and evolutionary design and achievement of indefinite life. They imply both an opportunity and a need for repeated infusions of new technology into the system. But how can this be done while keeping life-cycle cost within reasonable bounds? How much and what new technology should be included at the beginning? How much and what should be phased in later? How insure that the initial modules will readily accept new technology at a later time? How can maintenance, repairs, and modifications be performed without interrupting critical functions?

The answers proferred often involve the terms "transparency to technological change," "robustness," and "provision of functional interfaces." Unfortunately, such answers carry little useful knowledge, just new jargon.

Designers should take heart, however. Computer-aided design is proving to be a revolution, not simply because it is doing away with the drawing board and the gum eraser, but because it is eliminating a large fraction of the costly errors that occur during fabrication, by performing fit and form checks on the computer instead of with prototype or engineering models of the product itself. Extension of this kind of computer-aided modeling to the problems of repairability, maintainability, operability, and subsystem interfaces could greatly facilitate evolutionary change. Application of decentralized design wherein nearly autonomous subelements are linked through a common high capacity bus to a high level controller might allow service-oriented systems (power distribution, thermal management, communications, and stability and control) to adapt effectively to change. New ideas about design organization, associated with applying artificial intelligence, may likewise help formulate efficient evolution of a station.

Scientific, commercial and military uses generate a number of difficult and often conflicting design challenges. Scientists will insist upon a lean, quiet, disturbance-free environment, very precise pointing, and a high level of stability. Many experiments they will want isolated for long periods, and others given frequent attention as targets of opportunity present themselves or consumables approach depletion. A great deal of data will be generated. Should it be transmitted directly to the ground in real time or at more convenient opportunities? Should it be processed on the station? Should control of the experiments be from the ground, from the station, or automatic? Should scientific equipment external to the station be serviced by means of EVA, with teleoperators, or brought into a shirtsleeve-environment workshop? Commercial users may wish to restrict access to work of proprietary interest. They may have awkward power, heat-rejection, and resupply requirements. The military will, of course, demand security and priority. Satellite servicing will require that the station have the ability to fetch, dock, and restrain the satellite and then to provide the appropriate service such as refueling, repairing or replacing components, recharging or replacing energy storage devices, reconfiguring subsystems, refurbishing thermal-control coatings, etc.

For the long lived space station, life-cycle cost must drive design. Too often budgetary pressures have caused project managers to trade savings in initial development cost for large operational expenses later. Such trades made for the space station could price operations out of reach. Certainly the ability of the station to achieve at some time in its evolution a high level of autonomy will greatly reduce operational costs. Technological considerations should be brought to bear *now*, before it becomes too late. Currently, during on-orbit operation the Shuttle requires *hundreds* of ground controllers and mission specialists to monitor and supervise functions at a very detailed level around the clock. Each mission requires the generation of *volumes* of minute instructions, plans, and alternate plans followed by extensive simulations. Payload preparation is exceedingly thorough, tedious, and time-consuming. In short, space flight, especially manned space flight, continues to be very labor intensive. The technology to reduce the labor required is close at hand, but it must be focused on specific space-station requirements. That must be done *now*—and without simply trading ground controllers for software-maintenance specialists.

Closing of life-support water, air, and even food

cycles may also be economical in the long run because of cumulative resupply costs. The option to achieve those goals should not be ruled out by failure to address technology required now.

Constant access to solar energy causes some to dismiss energy efficiency as an important consideration. When life-cycle cost is considered, however, energy efficiency may well be a goal worth seeking. The most efficient power generation and distribution system will require the smallest possible solar arrays and thermal radiators. In turn, smallness will allow a low-drag configuration and minimum need for propellant for drag make-up. Small arrays and radiators will also simplify attitude control and stabilization. Energy-efficient systems tend to be longer lasting, entailing less heat, wear, and fatigue.

Another means to keep space-station operational costs under control may be to use the station itself as the test bed for most future growth developments rather than to maintain a ground-based high-fidelity replica.

Most form, fit, and function checks could probably be done by computer. It is not completely obvious that such an approach has advantages, but it appears attractive enough to warrant serious study.

As mentioned, we need a better understanding of man's ability to adapt to and function in the space environment. That calls for deeper understanding of man-machine interactions.

The final requirement relates to the proposed project schedule. We have only a few years to get technology to the necessary readiness without incurring excessive technical risk or residual development cost. We must array the technology options and set priorities to use available resources effectively. And we must coordinate the relevant programs of NASA, DOD, and industry to assure the most productive overall program. (The total industry IR&D effort already comes to several times that of the NASA-funded program.) In this respect, care must be taken to assess technologies that will phase in at later times.

A year ago, the SSTSC established nine groups to work out these needs, and added a tenth dealing with human capabilities last summer. Each working group has eight to ten technical experts selected from the NASA field centers conducting relevant activities and from the sponsoring Headquarters program office. Over the past year they have been assessing on-going R&T program plans, and recommending efforts for the FY84 NASA budget submittal. The chairmen of these working groups have written the articles which follow dealing with the technology challenges and opportunities. In their overviews you see the shaping of a new space era.

SPACE STATION TECHNOLOGY

DATA SYSTEMS

Optical Bus Will Connect Distributed System

By WILLIAM L. SWINGLE
NASA Johnson Space Center

As a general point, the engineers in aerospace know well the avalanche of emerging technology and technology products in information and digital-data systems. The space station will profit from this bounty, including recent advances in the generic technologies of automation, artificial intelligence, and so-called "expert systems."

While the space station proper will be an orbiting entity, in terms of data systems it forms but one element in a potentially large and complex network of distributed elements in a space operations system. F-1 gives a general idea of the potential scope of the distribution network. Besides the space station itself, the orbiting elements will include the Space Shuttle, communication relay and navigation satellites, orbital-transfer vehicles, extravehicular crew members, and tended free-flyers. Ground elements will include control centers, receiving stations, data archives, and a host of users, all demanding in some form or another data and some control access.

Ideally each user will have access to his domain of interest through a data system service that is stable, functionally transparent, and easily understood ("friendly") at interfaces. The local networks will be interoperable with cross-system access to distributed data bases in some reasonably automated fashion. Optimal use of automation will enable cost-effective performance of critical real-time functions, housekeeping tasks, mission planning, procedures development, and background analysis and service funtions.

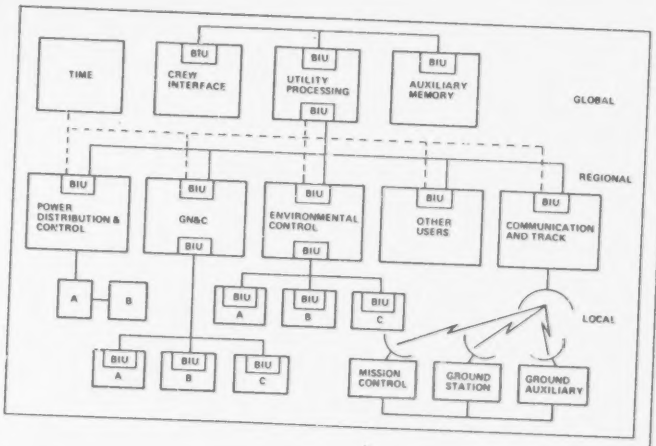
WILLIAM L. SWINGLE, as assistant chief of the Avionics Systems Div. at NASA-Johnson, manages division support of space station technology and advanced development. He played a large part in developing Apollo and Shuttle avionics.

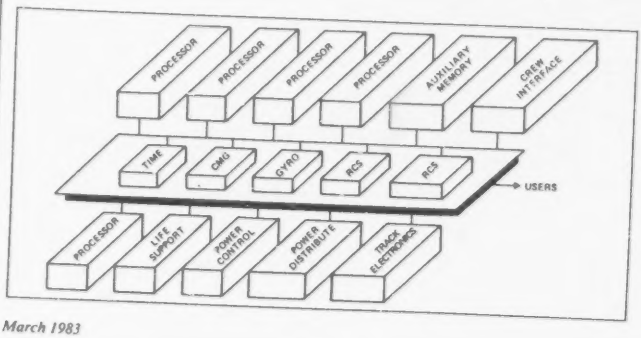
F-1 **Not the space station alone,** but rather a complex distributed network will characterize data systems.

The designer faces many problems in treating such an integrated system:

- All of the distributed network elements are in themselves complex regional-level networks with demanding requirements.
- The space station proper will probably involve at least three development phases: core-system and habitability modules, and operations facilities.
- The station and attached modules will be developed somewhat separately over its long life.
- The evolutionary pace of many of the existing local systems will be prejudiced by considerations of investment and immediate needs.
- The ground-user community will grow and change over the operational lifetime.
- All system elements will suffer pressures for

F-2 **HIERARCHICAL FORM OF ONBOARD DATA SYSTEM**





F-3 **GLOBAL FORM**

technology updates to improve productivity and combat obsolescence.

The onboard data system and other new elements to the network as they are developed should strive toward compatibility with idealized goals. The data system interfaces, services, procedures, and protocols need to be standardized and remain stable so that other parts of the system can be easily changed and upgraded later. In place portions of the ground systems should move toward these goals in some organized evolutionary manner.

There will be intense and continuing technology developments driven by needs and opportunities unrelated to space stations in commercial, scientific, and military areas. Continuing effort will be required to tap and adapt this evolving technology to the needs of space systems.

A technically adequate system might be designed using yesterday's technology along with off-the-shelf systems or system elements. This approach is not usually perceived as the most frugal, but it has a short handle.

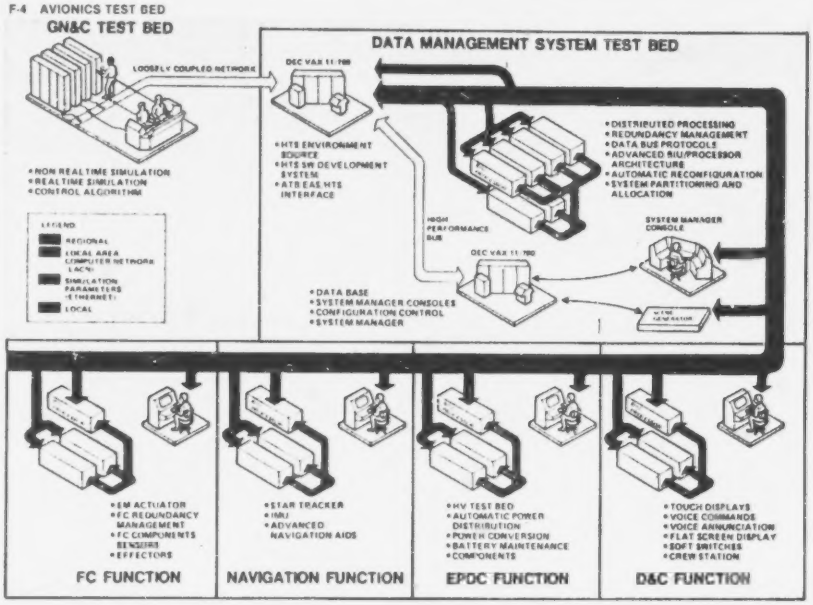
Selection of the most recent technology base will tend to optimize utility and operational program costs, but overly optimistic assessments of readiness will penalize development costs and manageability.

In general, extensive functional distribution, carrying out relatively independent smaller projects, can lower software and verification costs and aid manageability. It usually costs more, however, in terms of hardware and software resources. That calls for adroit use of standardization and commonality. There will be numerous opportunities to capitalize on the economies of commonality in terms of hardware, software, software tools and facilities, and verification. Inadequate memory and time margins can have an explosive effect on software and verification costs.

Fault tolerance is one of the more difficult technical areas to attack for all systems. The development of effective specifications involve reliability, function criticality, onboard maintenance, the environment, tolerance for operations downtime, Shuttle-revisit cycle time, and rescue.

"Verification" of both software and hardware/software systems will be major cost-drivers.

F-4 AVIONICS TEST BED



The evolutionary nature of the system along with the extensive volume of expected software are largely responsible for the scope of this problem, and running equipment up and down with the Shuttle will prove a costly way to solve it.

One concept of the onboard data system illustrates some of the technology challenges and activities.

The general topology is distributive. At least two approaches have been considered, and there are many more. F-2 shows a hierarchical concept. In it the interfaces between subsystems must be loosely coupled—no time-critical relationships beyond broad bus limits. One of the nodes will have a dedicated interface to a ground station under control of the onboard system. There is a separate timing bus as a common reference. Standard devices called bus interface units (BIUs) are assigned to subsystems. It is expected that the BIUs will handle the equivalent of least the first six network layers, as defined by the International Standards Organization. This will be an open system, with adaptive or autonomous nodes, so that expansions will be fairly transparent to users. Subsystem elements will probably employ embedded microprocessors for local services.

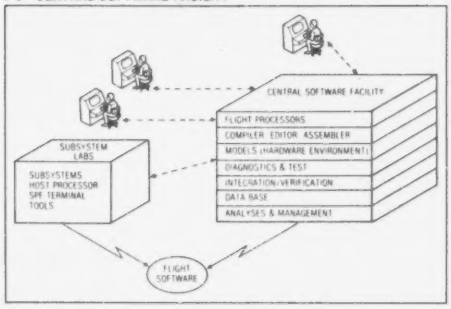
F-3 depicts a global approach with all processors interconnected to all sensors and controllers. The processor array can be viewed as a centralized multiprocessor. This scheme allows more flexibility and more efficient use of resources. However, functional separation is less explicit.

Application of wide-scale, open-system distributed architecture will be new to manned space vehicles. It will call for a major design effort. Eventual designs need to be supported by early proof-of-concept testing in representative arrangements. F-4 illustrates a concept for doing this employing most of the system concepts and technologies of interest. It includes the transport of software developed in an offline simulation into the test system.

The fiber optics buses will have data rates of at least 20 Mb/sec. Space qualification of candidate fibers and optical-bus components by NASA-Goddard is in progress.

The eventual network-interconnect scheme is uncertain. NASA has work in progress on star, graph, and ring type systems using electrical and fiber-optic media. A NASA-Langley effort on graph networks includes adaptive-fault-tolerant and self-correcting operations. A breadboard program at NASA-Johnson includes evaluation of the previously discussed BIU approach in an adaptive and fault-correcting chordal or concentric ring type network. Fiber-optics would allow an evolution to wave-length modulation. NASA-Langley is doing work on these components and systems.

F-5 CENTRAL SOFTWARE FACILITY



Auxiliary memory will probably use magnetic-bubble technology. Current NASA efforts concentrate on improving storage density and performing system level proof-of-concept testing. Access time, memory density, and reliability will be substantially improved over tape systems. Optical-disk (laser) systems will be assessed as a higher performance option.

No clear preferred strategy on processors for the space station has surfaced. Technology efforts involving alternate approaches to fault-tolerant processors are in the demonstration phase at Langley. The Jet Propulsion Laboratory has been doing advanced work on fault-tolerant computer modules.

Commercial and military development in microprocessors appear very suitable for space-station support; e.g., the Intel 432, Air Force Mil-Std 1750/9450, and Conklin chip-set developments. The 432 architecture looks highly desirable for multi-tasking and fault tolerance, particularly as coupled with Ada-supported software. Compatibility with space environments is an unresolved issue.

And, finally, software—a bugaboo on everyone's mind in terms of cost, program control, and reliability—raises concerns about adaptation of existing tools, standardization and commonality, management, "verification," criticality classification, interface stability, transportability, and automation (could create huge demand on software sizing). It will be a large order to come up with the right answers. The DOD software initiative that is built around the Ada programming language will provide one focus.

The concept sketched in F-5 would greatly aid software development and production. It would be accessible to subsystem users through remote terminals and a higher-order-language interface. Laboratories would use additonal colocated equipment as would be necessary.

SPACE STATION TECHNOLOGY

ELECTRIC POWER

Looking at Regenerative Systems

By J.L. MILLER
NASA Marshall Space Flight Center

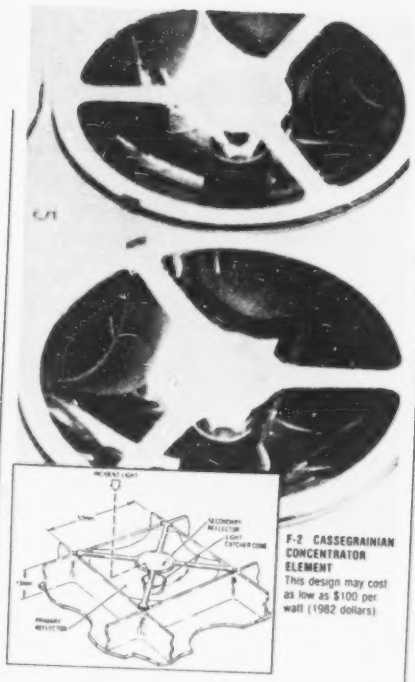
The Skylab mission taught the importance of abundant electrical energy for manned space operations. When it lost 25% of its power-generating capacity, the crew had to spend much valuable time juggling their activities to keep power demands within the capacity of the system. The cost of managing a large space system with marginal power is only half the problem. With ever-inflating costs of power hardware, the prospect of providing excess capacity decreases with each successive project.

For alleviation for a space station, two objectives have been incorporated into the electrical-power-system technology program: lowering of life-cycle cost and provision for autonomous management.

To understand the cost and management problems associated with space power systems, we must examine the system elements and consider operations associated with each: generation, storage, distribution, and control. A well-designed system will give the same type of electrical service as a commercial utility. A user should be able to turn his load on and off and expect it to receive electrical power and function normally with no other load being affected and with full assurance that the required energy will be available. An overload or other fault should cause only a minimum "blackout." Critical-load buses will be supplied through redundancy, providing maximum assurance of adequate power.

Also, analogous to the terrestrial electrical utility, the space power system needs a multiplicity of sources, storage elements, and distribution paths —so-called "vertical segmentation" (achieved by allocatng portions of the power-generation equipment to portions of the energy-storage hardware and feeding power through switch gear to multiple distribution buses). Prudent design dictates the cross-strapping of power-system elements to minimize the effects of hardware failures.

J.L. MILLER is chief of the Electrical Division, Information and Electronic Systems Lab at NASA-Marshall. He is a member of the AIAA Aerospace Power Systems Technical Committee and has a masters degree in electrical engineering.



F-2 CASSEGRAINIAN CONCENTRATOR ELEMENT
This design may cost as low as $100 per watt (1982 dollars)

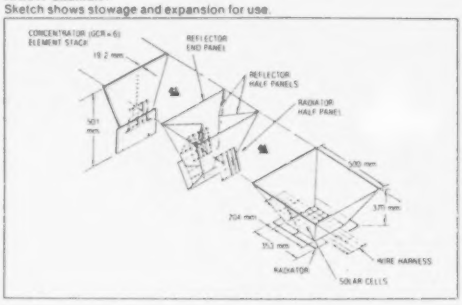
Large space-power systems capable of operating at low Earth orbit (LEO) for two to five years today have recurring cost of the order of $800 to $1,000 per watt (of orbital average power available from the system). This applies to a classical photovoltaic source with nickel-cadmium (NiCd) battery storage supplying 28-V d.c. power and with semi-automated control and management. Large numbers of silicon photovoltaic cells needed make the solar array the highest cost element of the classic source.

Chemical fuel cells and nuclear reactors with thermoelectric power conversion represent alternatives for electrical power generation. (Primary batteries are not an option due to their low specific energy, typically less than 100 Wh/lb.) The primary fuel cell is an attractive candidate since electrochemically it does not consume itself as primary batteries do but consumes resupplied reactants, such as hydrogen (H_2) and oxygen (O_2), at a rate of about 1.0 lb/kWh including purge requirements to clean out accumulated impurities. Today's cells lack the long life desired, and the system designers

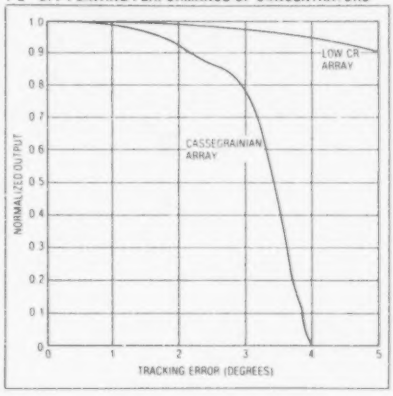
have not settled on a mechanism for resupplying fuel-cell-grade oxygen and hydrogen in orbit.

A nuclear reactor coupled with thermoelectric elements that convert heat directly to electricity offers efficiency in terms of specific power, but this type of system requires extensive development, and basic facets of it, such as operational safety and fission-product disposal, have not been sufficiently addressed. Thus the photovoltaic solar array dominates space-station planning for the late '80s. Even so, over the next few years much must be done to reduce fabrication cost and increase the life of arrays. The leading candidate for achieving these goals is the concentrator array, in which highly reflective surfaces concentrate solar energy onto the solar cells. Being less expensive than cells, concentrators with reflectances greater than around 0.85 should considerably reduce the cost per watt of generated power.

F-1 LOW-CONCENTRATION-RATIO (LCR) CONCENTRATING-ARRAY ELEMENT
Sketch shows stowage and expansion for use.



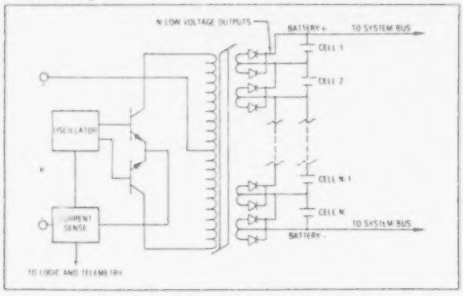
F-2 OFF-POINTING PERFORMANCE OF CONCENTRATORS



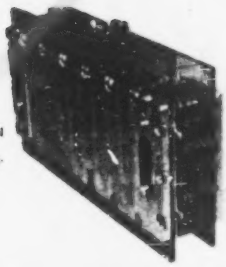
Two types of concentrator arrays are being considered. F-1 shows a concentrating array element having a low geometric concentration ratio (GCR) of 6. Considering reflector losses, it produces an actual solar flux density of about 5 Suns at the cell surface. The second type, see opening illustration, employs a cassegrainian concentrator to produce an actual flux level of about 100 Suns on the cell surface. It has a GCR of 120 before reflector and masking losses. Both types greatly reduce cost —from some $300/W for planar arrays to possibly $250/W for the F-1 design and perhaps as low as $100/W for the 100:1 design (1982 dollars).

The F-1 array can use cells similar to planar arrays, with similar techniques of cell bonding and interconnection. This array is relatively insensitive to off-pointing (F-2). It is considered a relatively low technology-risk for early space-station use.

F-3 BATTERY PROTECTION AND RECONDITIONING CIRCUIT
Simplified diagram.



The cassegrainian approach requires a new cell to be developed and new techniques of incorporating the cell into the system, in part because of the small size of cell used (only 4 mm in diam) and the fact that it operates at 100 Suns of solar flux and at a high current density (25 mA/mm²). Even at this high flux level, the cell does not require active cooling. Operating at a temperature of around 80 C and at 100 Suns of flux, the small GaAs cell under development for this array by NASA Lewis Research Center may yield an efficiency greater than 20%. Due to passive cooling, higher cell efficiencies, and good area utilization, the cassegrainian array offers a very attractive advantage over planar arrays—greater power output per unit area. A planar array can produce nominally 100 W/m². The cassegrainian approach should yield at least 125 W/m². That



F-4 BIPOLAR NICKEL-HYDROGEN FUEL STACK
Ten 0.24-sq-ft series-connected cells.

means less drag and therefore lower requirements for station-keeping propulsion.

The cassegrainian design presents a moderately high technology-risk for the initial space station. It requires a much higher degree of planarity than the F-1 design. Both require reflective surfaces that will suffer little degradation in the space environment. A comprehensive technology program managed for NASA Office of Aeronautical and Space Technology (OAST) by NASA Marshall Space Flight Center (MSFC) treats these problems, aiming for a concentrator array option for the initial station, and to verify the technology by test hardware.

High concentration ratios do not necessarily imply significant depth to the array. Cassegrainian array panel designed for operation at an effective GCR of 100 has a thickness of only 13 mm—about the same as a typical planar-array panel with a honeycomb substrate. It would have about the same packing density for launch. Moreover, cells of the cassegrainian array take only about 1% of the deployed area and, although considerably more expensive per unit area than cells for a planar array, produce energy at much less cost.

While the predominant problem in solar arrays has been cost, the big concerns in energy storage have been mass and lifetime. Historically, energy storage has been accomplished almost entirely by secondary nickel-cadmium (NiCd) batteries at a specific performance of around 8-12 Wh/kg. Very little progress has been made in the past decade in improving either the weight or life of NiCd batteries, although considerable progress has been made in understanding how to use the batteries and how to extend their life through protection and reconditioning. A typical NiCd battery operating at LEO would have an allowable discharge depth of 10-15% and a life expectancy of 3-5 yr.

Battery protection and reconditioning (see F-4), may extend NiCd-battery life to 8-10 yr, or more. Some 20-Ah, 28-V d.c. batteries have already demonstrated operating times of over 7 yr.

Even with such techniques this energy-storage option will continue to be a heavyweight approach. An attractive lighter alternative may be the bipolar nickel-hydrogen (NiH_2) battery under study at NASA-Lewis. This hybrid fuel-cell/battery uses a hydrogen electrode similar to that of the hydrogen/oxygen fuel cell to replace the cadmium plate in the NiCd system. Considerable work has been done by both Comsat and the USAF on a NiH_2 battery system for the relatively low cycle life GEO application, but only bipolar work has been aimed directly at LEO attempting to achieve both long cycle-life and increased cycle depth for the high-capacity energy storage devices needed for a space station. The system (F-4) resembles a fuel-cell stack. Tests of it yield watt-hour efficiencies ranging to 85%, compared to 80% for NiCd. The bi-polar NiH_2 battery should be packagable with a volumetric efficiency as high as that of NiCd but with perhaps twice the specific energy, at around 16 Wh/kg. Since the cadmium plate is the short-life component of NiCd, the NiH_2 system may also have longer life.

Another, even lighter system for energy storage is being pursued at both NASA Johnson Space Center and NASA Lewis. Unlike the hybrid NiH_2 battery, it uses two fuel-cell-related technologies. One fuel-cell stack operates as a power-generation source in the orbit's dark portion and converts reactants (H_2 and O_2) to electricity and water. Another stack operates in the electrolysis mode during the orbit's sunlit part to consume electricity and produce H_2 and O_2 by electrolyzing the fuel-cell-produced water. Called a regenerative fuel-cell/electrolysis (FCE) system, it offers a specific energy of 40 Wh/kg—more than twice the NiH_2 battery's specific energy.

Two of the very interesting potential uses of such technology are to provide emergency O_2 to the life-support system and to provide both H_2 and O_2 as reactants to the propulsion system. Also, since the electrolysis and the fuel-cell stacks are separate items, they can be tailored to the application needed. The first FCE breadboard is already undergoing test and checkout. The basic fuel-cell technology is well advanced, being used as the power source for the Shuttle Orbiter. Achieving adequate life should be the main problem with fuel cell-electrolysis.

Whatever the electrochemical energy-storage system chosen for the initial station, some changeout of hardware on orbit may be necessary. This is not viewed as a particularly difficult task. The 60-Ah NiCd batteries on Space Telescope, for instance, are designed as orbital replaceable units (ORUs) and should provide valuable experience in this regard.

The only non-electrochemical energy storage option under study, the flywheel, could be competitive with the specific energy of electrochemical options. With gas or magnetically suspended bearings the flywheel could have essentially unlimited life. Un-

fortunately, flywheel systems are not sufficiently developed to be serious candidates for the initial space station.

As to power distribution, the system must carry a voltage higher than the standard 28 if reasonable cable weights and distribution efficiencies of 90% or better are to be achieved. Higher voltages entail the primary potential disadvantage of interactions of exposed electrically conductive surfaces and the environmental plasma existing at the space station's operating altitude. The nature and magnitude of such interactions are under study.

The designer also faces an issue in choosing a.c. or d.c. voltage.

Two approaches to higher d.c. voltage have received the most attention. One holds that 135 ±15 Vd.c. is best considering battery reliability and available electronic components. The other advocates twice this level (270 ±30 Vd.c.) on grounds that distribution losses are only half as great and that the component-development problem will not be appreciably increased.

The a.c. choice will be more elusive since the designer may choose among numerous a.c. frequencies. A.c. offers ease of voltage transformation and the possibility of transmission at even higher voltages. On the other hand, the a.c. must be created since the source and storage devices, with the exception of inertial, produce d.c. Whether a.c. has enough advantages to pay for this extra inverter hardware remains to be seen. One interesting possibility is to locate the batteries, solar array, and inverters all on one side of the rotary joint (required for Sun tracking by the solar array) and transmit a.c. through the rotary joint by means of a rotary transformer. The other option is to use d.c. slip rings or roller rings.

NASA has begun a technology program to resolve the a.c.-vs.-d.c. question and to target an optimum voltage range. It should produce the much needed information by mid-1985.

Distribution of power through a utility-style network has certain desirable features. It entails automatic fault sensing and clearing, to keep the number of "customers" losing power to a minimum in the event of a fault. This requires the development of sensing and switching devices that do not yet exist. Also, the requirement to assure adequate power for critical loads as a first priority dictates alternate paths of transmission. Ability to balance the total load among several energy-storage devices to maximize life would also require alternate paths of transmission. One scheme for accomplishing this would be by flexible alternate-path design. Here, the load centers can be fed from any combination of main feeder buses, which lends itself to automated control of the distribution network.

Monitoring of the feeder-bus and load-center network and decisions for reconfiguration represent one of three primary areas of technology effort to provide autonomous control of the entire electrical power system. The other two areas are the energy-storage elements and control of power source. In large measure, these three areas are independent of one another, but sometimes interdependencies within or even outside the electrical power system decide operations. As noted earlier, feeder-bus loads can be balanced through load-center monitoring and switching. Also, some occasions will call for an imbalance in the system. Power quality is another factor that must be considered in power distribution; requirements for transient-free and/or isolated power will need to be accounted for in the autonomous control schemes.

NASA-Marshall has been assembling much of the data for this type of power management under parallel efforts. One seeks to identify the technology issues associated with autonomous control of power systems plus needs for specific technology advancements, as in sensing and switching devices, and for control laws for power-source and energy-storage management. The other investigates the application of "artificial inteiligence" to such complex areas as failure prediction and state-of-health diagnosis. A significant base of empirical understanding already exists through the operation of programmable power processors and power-system controllers. The next two years will be critical in establishing the level of automation that can be incorporated into an initial space station electrical power system and in identifying exact levels of technology risk.

In summary, affordability and manageability represent the foremost challenges in achieving the quantities of electrical power needed by a permanently manned space station. Technology programs in place since 1978 aim to lower the recurring costs of the primary power-system elements and to provide techniques for autonomous control of the overall system. Given sustained support they should yield major advancements over Skylab era techniques for application to a space station designed during the late '80s.

Acknowledgements

My thanks to the following individuals for valuable contributions to this article: Roy Lanier, James Graves, and Larry Crabtree of NASA Marshall Space Flight Center, Norman Chaffee of NASA Johnson Space Center, and Dennis Flood and Larry Thaller of NASA Lewis Research Center.

SPACE STATION TECHNOLOGY

COMMUNICATIONS AND TRACKING

Light and IR Will Help Carry High Traffic

By RICHARD M. DICKINSON
Jet Propulsion Lab
California Institute of Technology

Space-station communications and tracking encompass audio-microwave-infrared and optical-frequency subsystems. T-1 lists the many simultaneous potential space station users.

The many nodes of the space-station network range from the ground to nearby space to geosynchronous orbit (GEO), and their positions within the network will progressively change. Agile antenna pointing and tracking will be mandatory for nearly all external links.

The systems listed in T-1 will incrementally grow to at least ten different types of external links—different in range, information content and capacity, duty cycle, line-of-sight angles, RF interference, security, reliability, and carrier frequency. The system must handle simultaneous operation of from 10 to 15 links with up to 30 or more users. Internal links involve voice conferencing, biotelemetry, video, caution and warning, training and recreational, and personal communications.

The current station design thrust—toward increasing productivity and reducing the dependence on a large staff on the ground by providing more of an "operational" station in space—in effect requires an extensive tracking and communication center of its own in orbit. This center will acquire, process and distribute data, and issue commands and data necessary for operation with other space vehicles, notably teleoperated devices and vehicles.

Externally, the system aboard the station will be constrained to operate in a radio regulatory environment of power flux densities sufficiently low to protect established ground-based-equipment users. Competition for frequency assignments is severe. For example, the currently shared assignment of VHF frequencies for intermittent Shuttle extravehicular activity (EVA) may not be extended to the more permanent orbiting station. The long-wavelength VHF radiation is desirable for communicating around objects by diffraction. The existing S-band allocations for near-Earth space communications and tracking already are under pressure to vacate and to move to higher frequencies. Supporting umbilical-free EVA, particularly with extensive TV aids, will necessitate novel techniques and new technology at millimeter or laser frequencies.

Internally, the voice communications system must typically operate in the echo chambers resulting from the structures favored by pressure-vessel designers. The acoustic background noise from the life-support and cooling fans and pump motors can be significant.

The station must be designed and constructed to communicate simultaneously with and track the many vehicles and objects surrounding it in orbit. This requirement for space "traffic control" did not attend previous NASA missions. A vision of the many antennas sprouting from atop a typical airport control tower would not be a bad start for

F-1 Simultaneous operations involving many different vehicles, ranging out to geosynchronous orbit, impose complex communication and tracking needs. New and less expensive equipment will be needed for both the space station and its users.

RICHARD M. DICKINSON is on the staff of the Telecommunications Science and Engineering Div. of JPL and leads the lab's development of deep space communications. He supervised development of the Mercury-Venus 1973 X-band transmitter.

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T-1 SPACE STATION TELECOMMUNICATIONS

Core utility (housekeeping) services
Tracking and Data Relay Satellite System links
Extravehicular communication and manned maneuvering unit
Voice conferencing
Space Transportation System Orbiter links
Manned orbit transfer vehicle links
Consolidated network
Station public address
Station phones
TV work aids
Frequency and time distribution
Training video
Recreation video and audio
Rapifax/telepoint hardcopy/graphic

Teleoperations and vehicle services
Teleoperator maneuvering system communication, tracking, and navigation
Orbit Transfer Vehicle communication, tracking and navigation
Harbor tugs, communications, tracking, and navigation
Versatile service stage, communication, tracking, and navigation
Cherry picker, communications, tracking, and navigation
Frequency and time

Traffic control services
Surveillance
Vicinity tracking
Proximity tracking
Alignment/orientation
Navigation data
Guide beams
Dock/undock indicators
Rendezvous tracking
Global Positioning System data
Collection links
Frequency and time

Captive payload services
Telemetry
Command
Frequency and time
Video
Direct-to-ground links

Cluster telecom services
Telemetry
Command
Frequency and time
Video
Tracking beacons
Tracking aids
Direct-to-ground links
Navigation data

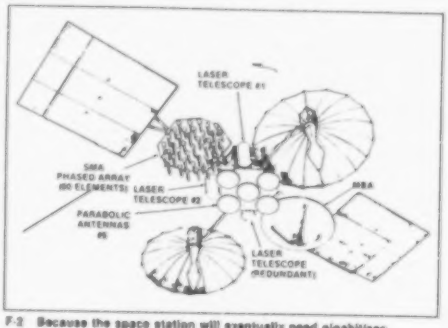
what the exterior of the space station might look like—except that the airport in space is not bounded on one side by the runways! Thus the spaceport "traffic control tower" must look even more like a porcupine to track objects anywhere around the space station. Whereas the Shuttle has 23 antennas, a first count gives the space station over 50 antennas. In addition to Shuttle-compatible equipment at P, L, C, S and Ku bands, the station system will likely have Ka, W, IR and optical-frequency equipment for communications and tracking.

Affordable, space-qualified, steerable phased arrays at RF and optical frequencies are key technology elements for improving productivity and reducing station life-cycle costs related to communication and tracking. Very wide band scientific and applications sensor data-rates also are a problem.

The space station must possess the communications to support the command and telemetry requirements of onboard or captive payloads. Earth sensing, earth resources imaging, astronomy, materials processing, video and other telepresence tasks will require many megabit-per-second channels. Space-station links using existing Shuttle or Landsat equipment to relay signals through the Tracking and Data Relay Satellite (TDRS) can only provide 50 or 300 Mb. TDRS is limited to 300 Mb delivered to the ground at White Sands, N.M. The station obviously needs higher data rate equipment. A more powerful TDRS (F-2) is being studied.

The space station may additionally need to provide the relay equipment for collecting and aggregating telemetery data from a growing fleet of formation flyers around it. That would free the local platforms from having to provide the high-gain, accurate pointing required to make high-data-rate links via TDRS directly. A link of modest pointing requirement and low power should suffice for local platforms and be less expensive to the user. This service could use less expensive wideband equipment at millimeter or laser frequencies. Also, relay links will be needed to TDRS and direct links for data dumps from store-and-forward units direct to users. Uplink color TV and 10^{-9} bit error rate computer data exchanges may require more than the TDRS's 25-Mb/sec uplink.

Regarding traffic control, the Shuttle-era K-band radar can only track a single object at a time to within a minimum range of about 30 m. Technologies exist to track simultaneously several objects at once, but they have not yet taken the form of space-qualified hardware. Also, tracking must extend down to contact or soft-docking ranges. A multifunction radar will be desirable for surveillance of



F-2 **Because the space station will eventually need gigabit/sec** channels, and the TDRS can handle only about 300 Mb, NASA has been studying a more powerful version of the tracking and data relay satellite.

the space around the station. Docking and departure operations will require long-range (2,000-km) acquisition and tracking for traffic control, medium-range (600-km) rendezvous and proximity range, angles and rates, and other orientation data.

A tracking scheme to follow or locate items such as loose tools or construction materials may be necessary to prevent collisions or hazards in the traffic regions about the station. Likewise, we will have to

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decide what to do about these loose objects.

A challenge in the design of microwave and laser links for the space station will be to keep the flux density directed toward personnel and the ground below permitted levels. Combined with the requirement for spherical coverage, this makes the design task particularly acute for EVA operations, but applies also to command and control and tracking while the station is conducting docking and departure operations.

It will be a design challenge to place the many separate antennas and lenses and reflectors about the station external geometry to give adequate overlapping fields of view (FOV) to permit spherical coverage and to radiate unambiguous navigation guide beams and markers. Adaptive arrays with distributed elements may solve the problem. Provisions should be made for distributed elements on modules added later to the station. Control of an adaptive array will require technology developments to produce much more rapid and accurate programs for predicting antenna patterns. Such programs will be necessary to determine the selection, RF phasing, and amplitude weighting of the various signals to be combined to yield the needed simultaneous coverage.

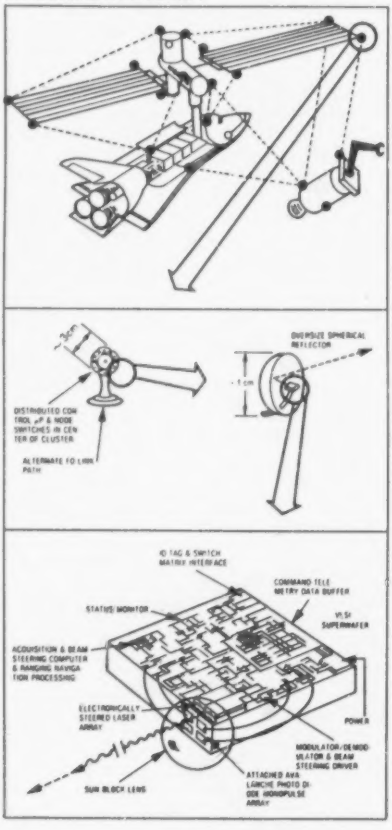
In addition to the radio frequency interference (RFI) and range-change effects on signal strength, the communication and tracking link designs must contend with multipath reflections and blockage from the Shuttle Orbiter and orbit-transfer vehicles (as well as adjacent moving structures such as solar panels). We will need more efficient signal design or coding techniques to permit reliable tracking and communications through the variable delays and interruptions.

A most pressing near-term requirement, however, will be for a voice conferencing system able to handle up to 20 people. Conferences must be controlled by voice inputs, with command-authority recognition and stress monitoring built into hands-free, umbilicalless units. Voice-recognition techniques, equipment, and wireless mikes exist, but the combination and the control software for a man-rated space system have not been demonstrated. IR scatter technology appears attractive.

One approach to spherical coverage involves the use of switched low-gain or "omnidirectional" antennas that broadcast or receive RF energy over a very wide range of angles, (perhaps pi steradians). Since the RF energy is diffused over a wide angle, the intensity in a given direction will be weak. The tendency to maintain performance over the weak link will be to increase the power out of the transmitter. However, this action also increases the power flux density intercepted by the Earth. This constraint limits the link performance. Spread-spectrum techniques reduce the spectral flux density and allow multiple access, but at the expense of complexity. An alternative might be multiple directive antennas for the space station.

Directive antennas require a more precise pointing system and means to acquire and track a target. One option, mechanical pointing of the antenna, requires that the structure to which it is mounted be capable of reacting the steering forces imparted to it. Another option, electronic steering (as with a phased array of low-gain elements), will be more

F-3 SURVEY SYSTEM CONCEPT


DISTRIBUTED CONTROL μP & MODE SWITCHES IN CENTER OF CLUSTER
ALTERNATE TO LINK PATH
DIFFUSE SPHERICAL REFLECTOR
IR TAG & SWITCH MATRIX INTERFACE
COMMAND TELEMETRY DATA BUFFER
STATUS MONITOR
VLSI SUPERWAFER
ACQUISITION & BEAM STEERING COMPUTER & RANGING NAVIGATION PROCESSING
ELECTRONICALLY STEERED LASER ARRAY
POWER
MODULATOR/DEMODULATOR & BEAM STEERING DRIVER
SUN BLOCK LENS
ATTACHED AVALANCHE PHOTO DIODE MONOPULSE ARRAY

costly at first, but may prove more cost-effective over the lifetime of the system. Also, wide-angle multiple-beam phased arrays are a highly desirable option to serve many users. The narrow-scan multibeam antenna technology from communication satellites will not meet the needs here.

Many technology options can serve the tracking needs. In addition to tracking information relayed from ground-based equipment or from TDRS, the space station will require its own means of obtaining metric tracking data. Skin-track radar will most likely be used. Beacons will be desirable for enhancing radar return; they will need codes for vehicle identification and other navigation aids such as heading, range to other objects, and orientation. Even passive echo-enhancement devices, such as corner reflectors, may be desirable.

Coherent radio transponders with simultaneous ranging channels can also be used for metric tracking by Doppler and ranging techniques. Interferometric techniques employing antennas located at the extremities of the space station would allow high-angular-resolution tracking of users about the station as well as produce navigation guide beams.

The global positioning system (GPS) may be available to provide position information both for the space station and its users. Individual data links will be needed in this connection.

Lidars (laser radars) will also play a role in tracking.

Tracking from ground-based radars, NORAD data, the consolidated network, and TDRS will be required for objects that pass out of view of the space station or are at extreme ranges.

All this remains to be studied in detail.

Many communication and tracking activities will involve only space-to-space links. These are candidates for optical or IR service. Solid-state lasers and avalanche photo diodes offer the advantages of low power, light weight, long life, small size, and potentially low cost (see F-3). Another benefit of the laser links would be less sensitivity to growing (perhaps factor of ten by 1990) RFI.

Nevertheless, the optical links will have to be designed to accommodate a form of RFI of their own due to blockage and reflections from materials in space, such as adjacent structure and the products of thrusters and expulsions from other processes (e.g., open-loop life support subsystems). Both data storage and alternate routing will be required to handle changes in the optical-link propagation path. Certain coding practices with error-correcting schemes will be applicable.

Thus, a tradeoff exists between optical and microwave systems. Millimeter-wave systems would be the alternative for wide-bandwidth links (due to pressure on lower-frequency microwave systems for other types of service). For military payloads, laser links will provide a degree of security against interception because of their narrow beams.

High-data-rate experiment telemetry that does not require real-time return can be recorded aboard the space station and returned on the next Shuttle flight. Data could also be processed aboard the station to reduce the quantity to be transmitted. Alternatively, the data could be sorted and dumped at high rate during the next available pass over the user's premises if it has compatible receiving and tracking equipment.

A major technology challenge will be to reduce the cost of electronic beam steering for both RF and optical-frequency phased arrays. Techniques such as monolithic microwave integrated circuits and VLSI computational modules will help, but additional cost-effective fabrication and assembly techniques will be required, particularly for power generation and phase-shifting devices. Techniques will be needed for fabricating and cooling two-dimensional arrays of solid-state laser diodes.

A great challenge will be to produce more efficient and lower cost millimeter wave devices by photolithographic techniques. Such equipment would benefit the wideband, high-data-rate links required on space station.

Similarly, we will need faster algorithms for producing accurate antenna-pattern prediction codes. Success would benefit FOV architectural design and adaptive tracking and communications.

Ability to design and produce lower-cost dual or multifrequency antennas would allow fewer pressure-hull penetrations and less real estate devoted to antenna farms.

In summary, the space station will initially employ the communications and tracking equipment and systems designed for past space vehicles, such as the Shuttle Orbiter, Landsat, TDRS, and some commercial and DOD satellites. But before long better systems will be needed. Constraints will force a move to higher RF and optical frequencies. The greatest challenge will be to develop *affordable* RF and laser electronically steerable phased arrays. These will increase productivity and permit the low life-cycle costs needed to support spherical-coverage operations for space traffic control, EVA and teleoperations.

The research described in this article was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

SPACE STATION TECHNOLOGY

CONTROL

Demands Mushroom as Station Grows

By STEPHEN Z. SZIRMAY
Jet Propulsion Lab
California Institute of Technology
and
JAMES BLAIR
NASA Marshall Space Flight Center

The initial space station will be composed of structurally rigid and nonrigid modules, rotating elements, and flexible appendages. As the station evolves, the configuration will change to reflect new missions, embracing both old and new elements. The station will experience environmental disturbances from the atmosphere, gravity gradient, the magnetic field, and solar radiation. It will also occasionally experience self-generated disturbances —docking forces, vibration from construction, and various perturbations from crew motion, station venting, payload articulation, and attitude or reboost maneuvers.

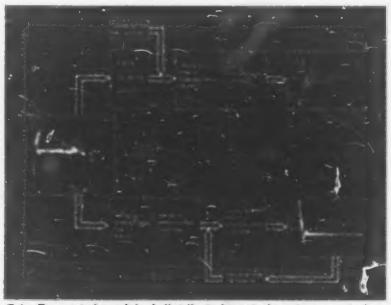
Control functions for the original space station may include attitude control, docking and berthing control, and system monitoring and management. As the space station evolves and mission objectives become more ambitious, control functions will multiply to perhaps encompass these:

- Attitude control and stabilization.
- Large space structure controls.
- Articulation control.
- Autonomous navigation.
- Space traffic control.
- Systems monitoring and management.
- Manipulator control.
- Teleoperator maneuvering system control.

STEPHEN Z. SZIRMAY, far left, manager of the Automated Systems Section, has been with JPL since 1956. A graduate of New York Univ., BSEE, 1954, he leads R&D in control of large space structures, robotics and teleoperators. JAMES C. BLAIR, deputy director, Systems Dynamics Lab, joined NASA-Marshall in 1963. A member of AIAA s Guidance and Control Technical Committee, he holds M.S. and Ph.D. degrees in electrical engineering from the Univ. of Tennessee.

Levels of control technology for the space station will depend on its evolution. Current control technology may suffice to fly the initial space station. But in order to ensure the ability of the station to grow without expensive retrofit or control redesign, the original control system must have architecture and interfaces compatible with future control technology. As structural elements are added, modular/distributed control will be required. When the configuration complexity, nonlinearity, and flexibility of the station become significant, onboard system identification techniques will be required to provide adequate information about configuration and dynamics. Adaptive techniques will probably be needed to control station dynamics.

Advanced control technology will be needed not only to enable graceful evolution, but also to gain



F-1 Truncated model of distributed control system must show the predictable performance indicated in the bottom part of diagram. Top indicates unstable or unpredictable behavior.

better performance, higher reliability, lower cost, and lower risk. It will be pivotal in developing automated systems that reduce ground support.

Principal challenges in these areas of control system design will be:

- Automated management of a highly complex man/machine system.
- Precision pointing and stabilization for a nonrigid structure growing progressively in size and complexity.
- Modular systems of high reliability, long life.

These needs call for hierarchical control, distributed modular control, autonomous real-time systems identification, vibration control, adaptive control, intelligent man/machine interfaces, and high-reliability, long-life hardware. T-1 enumerates all advanced technologies required. These technologies must be evaluated to demonstrate performance and

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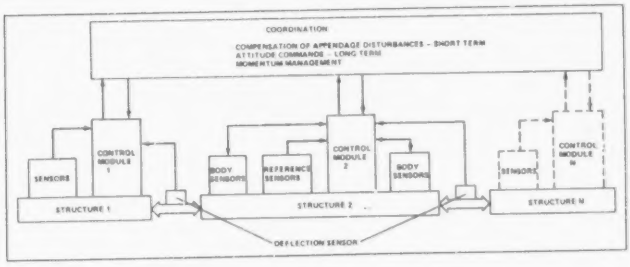
T-1 SPACE STATION ADVANCED TECHNOLOGY REQUIRED

Attitude Control & Stabilization
Autonomous station keeping
Orbit maintenance/reboost control
Adaptable control system design
Model order reduction
Multi-objective robust controller design
Momentum management
Long-life high reliability sensors and actuators
High precision sensing and actuation
Fault tolerant/redundancy designs
Large Space Structures Control
Adaptive/modular control
Distributed control
In-orbit systems identification
Active vibration control
Advanced state estimation
Flexible body/modal determination and control
Shape determination/control
Systems Monitoring/Management
Autonomous system supervision/maintenance
Autonomous self test/diagnosis
Subsystems control hierarchy
Redundancy management
Autonomous man/machine decision control
Autonomous system configuration control
Manipulators
Berthing management/control
Telepresence systems
Teleoperator/robotics systems
Computer vision systems
Robotics sensors/actuators
Teleoperator Maneuvering System
Autonomous navigation/rendezvous
Autonomous intelligent attitude control
Robotics system/attitude control integration
Articulation Control
High precision sensing and actuation
High stability precision pointing
Autonomous platform pointing control
Navigation
Autonomous navigation
Autonomous orbit determination
Multiple satellite formation orbit control
Space Traffic Control
Multiple vehicle control hierarchy
Rendezvous/approach management
Docking control

F-2 MODULAR CONTROL CONFIGURATION



identify risk and life-cycle cost.

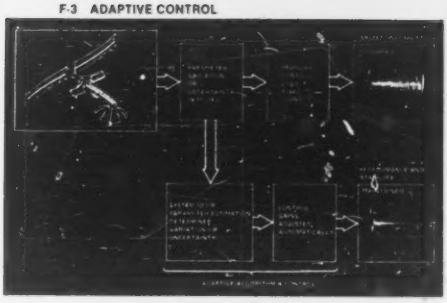
Distributed control techniques are used to actively stabilize large space structures which must be characterized by models having very large dimensions. Current approaches use a truncated model of the large space structure. Evaluations with the original, very large dimensional model, often show unpredictable or even unstable performance (see top of F-1) due to model truncation errors. An advanced distributed control begins with the *infinite* dimensional model of the large space structure. The initial distributed-control law obtained will also be dimensionally infinite. This control law must be truncated to a finite dimension and the truncation must yield predictable performance as illustrated on the bottom of F-1.

Modular control (F-2) represents an attractive way to add space-station elements efficiently with minimum impact on the existing control system configuration. An individual module would have its own control subsystem (actuators, sensors, control computer, etc.) and a "supervisory" controller would coordinate the modules. Including a new module would then require only addition of that subsystem and reinstruction of the supervisory control. Progress on this concept has been encouraging. A system with certain restrictions has been simulated and is being improved.

The initial dynamic model used in control design will contain uncertainties in structural stiffness, damping, and fundamental vibration frequencies, and the station will be changing dynamically during its operation. These variations may degrade the performance of standard control designs, to the point of instability (see top of F-3). To get around this problem, system identification and adaptive control can be used. System identification means determining type order and parameters of a system from measurements. An adaptive controller can update control and filter gains and maintain system stability as illustrated on the bottom of F-3.

The station's control system will likely include devices such as control-moment gyros, or reaction wheels which absorb external torques in the form of angular momentum. These devices work best when the external torques have strong cyclical components as do aerodynamic and gravity gradient torques. F-4 shows effect of aerodynamic center of pressure on momentum storage. Storage requirement is given in terms of the number of 3000-nms control-moment gyros (CMGs) required to fly the illustrated platform in an inertial orien-

F-3 ADAPTIVE CONTROL



tation with the longitudinal axis perpendicular to the orbit plane.

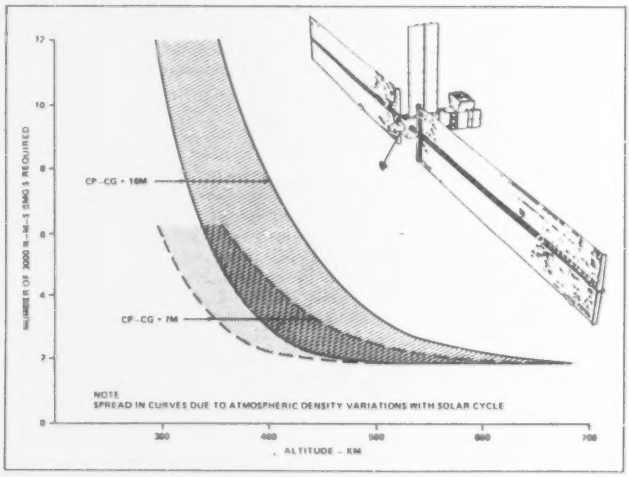
Large solar arrays dominate the aerodynamic forces, and the torques thus depend on the displacement of the system's center of mass from the center of pressure of the solar arrays. Data are given for payloads that cause displacements of 7 and 16 m. Since the aerodynamic torque varies with the ambient atmospheric density, and the density depends not only on altitude but also on solar activity, F-4 shows a range of CMG requirements. The upper bound for each configuration represents the requirement during periods of high solar activity. The lower bound applies to periods of low activity. As these atmospheric conditions become better known, the operating limits of the control system can be defined better.

Because of the sensitivity of large configurations to the many environmental moments, station geometry selection should consider momentum storage requirements. For maximum efficiency, the momentum-management system should try to offset one disturbance with another and thus minimize the storage requirements.

T-2 indicates typical momentum-desaturation capacity of several sources. Magnetic torquers are versatile, but have power and weight penalties. Gravity gradient and aerodynamic torquers have axes limitations, depending on the mode and orientation flown. Because the payload and experiment requirements are not known yet, no cyclical momentum terms are planned for a momentum-desaturation scheme. Effort should be concentrated on deriving a three-axis momentum desaturation technique using a combination of all three sources. Technology development will be needed for automating the momentum-management system, to reduce ground support requirements.

A hardware and software test bed will prepare the emerging technology for application. The guidance, navigation and control (GN&C) test bed will be an evolving simulation facility permitting selective substitution of actual GN&C software and hardware components in place of computer simulation elements. It should identify issues that drive design and performance requirements, specifications, and

F-4 AERODYNAMICS EFFECTS ON MOMENTUM STORAGE
For two sets of payloads, giving displacements of center of mass from center of pressure of 7 and 16 m.


NUMBER OF 3000 N-M-S CMG'S REQUIRED
CP-CG = 16M
CP-CG = 7M
NOTE
SPREAD IN CURVES DUE TO ATMOSPHERIC DENSITY VARIATIONS WITH SOLAR CYCLE
ALTITUDE - KM

T-2 MOMENTUM DESATURATION CAPABILITIES FOR INERTIALLY ORIENTED VEHICLES

Source	Momentum axis	Desaturation capability
Gravity gradient	In orbit plane	Nms per orbit per deg. of principal axis rotation
25 kW power system		100
Science/applications platforms		330-550
Skylab		600
25 kW power system and Shuttle		2200
Space station		Probability >800
Aerodynamic moment	Perpendicular to orbit plane	Nms per orbit per deg. of solar array articulation
Platform with 686 m^2 array area (435 km alt.)		250 at minimum density 800 at maximum density
Magnetic moment	Axis relative to torquer orientation	Nms per orbit per bar
Space telescope torquer bar (30 W, 50 kg)		800

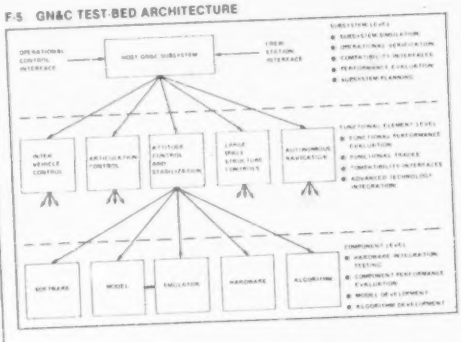
critical interfaces, and allow standardizing an approach for test and evaluation of GN&C options. Also the test bed will provide a means of transferring GN&C technology into the station development program throughout the life of the station.

In construction, the GN&C test bed will take a hierarchical form, paralleling the definition of the entire GN&C system (F-5). At each level the requirements on the constituent elements will be levied in the form of simple models designed to operate together as software modules within the simulation program. The modules will be usable independently and could be developed in isolation as long as the interfaces and functions are preserved. Modules within modules will be appropriate as long as they do not violate nesting constraints within the hierarchical structure. Each module in this early test bed will represent an identifiable element of the GN&C system and, depending on its depth within the model, could represent anything from a piece of hardware, such as an actuator, to a subsystem, such as an articulated instrument platform.

Another feature of the test bed will be its ability to substitute any given module and all of its nested constituents with a functionally similar but simplified version of the same element. Thus, not only will it be able to run subsets of the model independently, but also run the model at any level without the overhead associated with extraneous details.

The attitude stabilization and control "sub" test bed will be comprised of facility computers, environment simulators for control system hardware, and flight-type control hardware and software, including sensors, actuators, and flight-control computers. It will be used with increasing levels of fidelity. In early phases of assessment, its computers will allow total simulation. Hardware and environment simulators, such as the three-axis motion table, can be substituted for computer math models as development progresses and the test bed achieves higher fidelity. Tasks to be performed on the sub-test bed include assessment of control laws—taking in structural stabilization, momentum management, and distributed and modular control—derivation of component requirements, prototype testing, fault isolation, testing of components, system integration and interface testing, and software checkout.

F-5 GN&C TEST-BED ARCHITECTURE

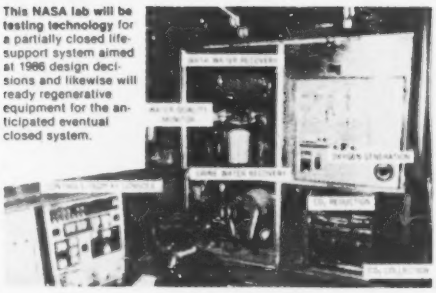


Major challenges in control technology development arise from the need to cope automatically with the highly complex space station, the configuration of which will be changing in orbit. To meet these challenges, significant advances in distributed control, adaptive control, modular control, system identification, fault-tolerant reliable hardware, and other technologies are required.

The test bed will widen options for GN&C development by bringing technology elements to a state of readiness and evaluating designs on a common basis. It should efficiently bring technology into the mainstream of station development—ensure "technology-optimal" design for growth, high performance, and minimum life-cycle cost.

Acknowledgement

The contributions of Yu-Hwan Lin of the Jet Propulsion Laboratory and Harry Buchanan, Stanley Carroll, and Miriam Hopkins of Marshall Space Flight Center are gratefully acknowledged.



This NASA lab will be testing technology for a partially closed life-support system aimed at 1986 design decisions and likewise will ready regenerative equipment for the anticipated eventual closed system.

SPACE STATION TECHNOLOGY

ENVIRONMENTAL CONTROL AND LIFE SUPPORT

Partially Closed System Will Save Big Money

By WALTER W. GUY
NASA Johnson Space Center

The environmental control and life support system (ECLSS) for the space station embraces basic requirements for atmospheric revitalization, atmospheric control, cabin thermal control, metabolic water, hygiene and waste, EVA support, and galley support. The first three maintain the living environment. For atmospheric revitalization, CO_2 must be continuously removed from the atmosphere together with other metabolically-produced gases. Oxygen used in the metabolic process must be replenished along with the oxygen and nitrogen lost due to cabin leakage. Atmospheric control mainly concerns cabin pressure and the composition of its constituents along with the monitoring of atmospheric trace gases and airborne microbiological contamination. Thermal controls remove heat from the cabin, ventilate it, and set humidity.

Metabolic water, both required and produced, must be collected, processed, and readied for reuse. It involves collection, reclamation, sterilization, quality monitoring, and stowage. Sources of metabolic water include perspiration, respiration, and urination. Other sources associated with crew hygiene include hand washing, bathing, oral hygiene, and laundering. Solid and liquid wastes associated with life support must be collected and processed. So must wastes from the galley. This includes refrigeration and freezing equipment, ovens, food processes, trash compactors, and dishwashers. The galley thus interacts with the metabolic and hygiene-water areas. Food and beverage preparation requires potable water. Clean-up requires water from the hygiene area while adding to waste water to be processed.

WALTER W. GUY (M), chief of the Crew Systems Div. at the NASA Johnson Space Center, has responsibility for developing spacecraft environmental and life support systems and astronaut intravehicular and extravehicular support equipment.

ECLSS also supports extravehicular activity (EVA), providing water, oxygen and waste stowage for the space-suit life support system, recovering consumables from EVA byproducts, and scavenging atmospheric gases from the vehicle's airlock.

Degree of ECLSS Closure: It is not obvious which of the crew's needs should be provided from the Earth (with the associated logistics penalty) or recovered in orbit from metabolic byproducts. In other words, what degree of system closure will be "optimum"? Arriving at a judgment involves tradeoffs of program risk, weight and volume, and life-cycle costs, and includes a fundamental life-support-system decision: whether to regenerate food from wastes. Current space-station planning involves a 1986 phase-C/D start. We lack the technology for food regeneration. Attempting to secure it by 1986 entails a relatively high risk. Thus supplying food from the ground must be considered an "optimum." In contrast to food, the other basic life-support requirements can be generated on board the space station with technology now being demonstrated. In fact, any of several concepts can provide oxygen, carbon dioxide removal, and water for drinking and washing.

Taking weight and volume as the primary decision factors brings the launch and logistic penalties of providing life-support requirements to the forefront in the determination of "optimum." Ground rules should be established in order to compare penalties for "open" and "partially closed" life support.

Although the space station has not yet been defined completely, the following conditions represent a realistic set of such groundrules: crew size of eight, resupply interval of 90 days, initial launch includes expendables for first resupply interval plus 30-day contingency, drinking water provided at 7.86 lb per day per person, wash water for morning hygiene at something less than a pint, and the same for two additional handwashes per person per day.

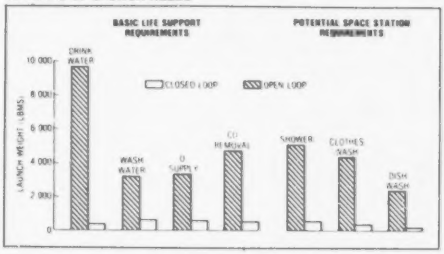
Recent studies have taken the Shuttle design as state-of-the-art for estimating tank-storage penalties, packaging weights, consumable weights, and metabolic/hygiene requirements. Weights for re-

generative life-support subsystems (their process efficiencies and expendables requirements) were taken from advanced laboratory hardware available today. This laboratory hardware was not designed to meet flight weight specifications so the comparisons to be presented should be conservative.

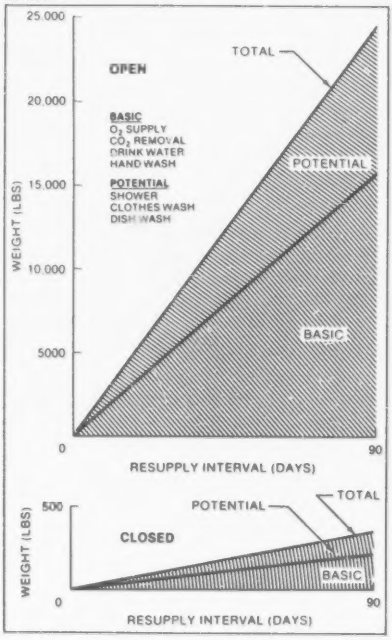
F-1 and F-2 compare open and partially closed life-support launch and resupply weights for basic requirements using the groundrules given above. A typical open-loop, Shuttle-type life-support system incurs a dramatic penalty over a partially closed system of today's technology. From an overall standpoint, a partially closed system will save almost 20,000 lb of launch weight and a further 15,000-lb saving at each resupply interval.

Several additional requirements concern onboard regeneration. Water which enables the crew to shower every other day as well as water for clothes-washing and dishwashing could be recycled by water-reclamation systems using existing technology. Although perhaps not mandatory, water reclamation would eliminate hygiene wet wipes, disposable clothes, and disposable trays and utensils for food service and thus save weight and volume—some 10,000 lb more in initial launch weight and at each resupply interval.

F-1 OPEN VS. PARTIALLY CLOSED LIFE-SUPPORT SYSTEMS IN TERMS OF LAUNCH NEEDS



F-2 RESUPPLY WEIGHT FOR OPEN VS. PARTIALLY CLOSED SYSTEMS

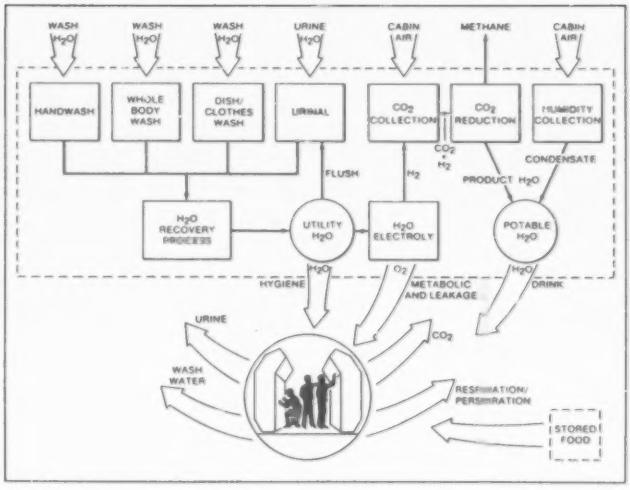


This appraisal strongly suggests that a partially closed life-support system would be "optimum." However, life-cycle costs must also be evaluated. Assuming that a single Shuttle launch costs about $60 million for a 60,000 lb payload, each pound in orbit costs nominally $1000. A partially closed life-support system thus saves about $80 million by the end of the first year of space-station operation. We conservatively estimate that the design, development, test, and evaluation (DDT&E) for a partially closed life-support system would cost $80 million more than for an open-loop system. Therefore, over the first 10 years of space-station life the partially closed life-support system will save over $700 million (even discounting inflationary effects).

In short, program risk, weight and volume, and life-cycle costs favor partial closure of the life-support system. F-3 depicts the concept for a partially closed life-support system. This scheme gives the crew high-quality water to drink and and recycles the nonpotable wash water. It recovers water from washing hands, body, dishes, and clothes and flushing the urinal. Excess water from the recovery process is electrolyzed to provide metabolic and leakage oxygen. Hydrogen from water electrolysis is used, as needed, in the CO_2 collection and reduction processes, which produce methane (or carbon) and chemically-formed water. The crew drinks electrolysis water and moisture condensed from the atmosphere during humidity control.

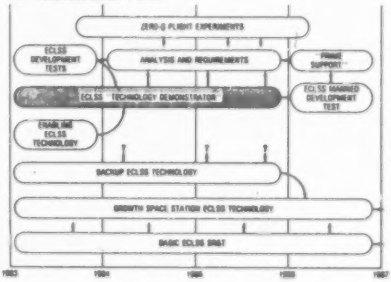
ECLSS Configuration: Other space-station design "parameters" can affect the configuration of the environmental control and life support system. Consideration is being given to the use of a regenerative fuel cell to augment solar arrays for nightside power. The fuel cell in this mode does not

F-3 PARTIALLY CLOSED SCHEME UNDER DEVELOPMENT



consume reactants; the water it produces is subsequently electrolyzed to regenerate the reactants for the next darkside pass. The crew could also use this water. For a nominal 50-kW nonregenerative fuel cell almost 90,000 lb of reactants would be required each 90-day resupply interval. Thus, the byproduct water provides more than six times the amount of water needed for drinking, crew hygiene, and clothes- and dishwashing. With so significant a weight penalty for reactant resupply, the open-loop fuel cell would *not* be an intuitive choice for space station power. However, should large-scale solar-array technology falter or the evolving needs of the space station dictate fuel cells as the electrical power system, the ECLSS would not require any water-reclamation subsystems.

F-4 TECHNOLOGY PLAN



The reality of funding availability for technology development, the implied risk of new technology to project cost and schedule, and the promise that evolution means acceptance to change over time might delay initial incorporation of the "optimum" ECLSS. Early during buildup of the space station a small crew could use a flight-proven Shuttle-type system. Only when the station has a larger permanent crew would the advanced, partially closed system be required.

Two aspects of each new ECLSS subsystem concept must be evaluated as the station begins to build up. First, is the subsystem efficient in terms of energy or expendables, or more reliable than a subsystem already on board? If so, can it be configured to meet the interfaces of the already installed system? Secondly, does the new subsystem concept perform previously unavailable functions? Will it improve process flow without a redesign of the basic system?

Technology Challenges and Opportunities: The ECLSS presents two main technology challenges: to achieve technology readiness for design and to prove that a firm commitment can be made to technology which has never flown in manned spacecraft. These challenges entail several subtle issues of automation, maintainability, commonality, and reliability. They must be resolved in a way that allows

space-station crew to treat the life-support system like a utility requiring only preventative maintenance, and not have it occupy a primary position in their day-to-day activities, simply because it must necessarily sustain their lives.

Each challenge may also be viewed as a management opportunity. The need to achieve technology readiness presents a chance to plan and organize a technology program sharply focused on space-station requirements. The program will bring the technology beyond laboratory demonstration of critical functions or characteristics through testing of an engineering model in a simulated or, if necessary, the actual space environment.

With the near-in, 1986 space-station start, only subsystems now in some stage of development will have any real opportunity.

The second technology challenge, proving technology readiness, encourages systematic demonstrations. Three are planned. In the first, a laboratory demonstration of the long-life characteristics, each test article will be a scaled-down subsystem embodying the "heart of the process." This family of life-test modules will be run continuously throughout 1983, 1984, and 1985, with periodic checks to measure any loss in process efficiency. By the 1986 space-station start, much data will be available to instill confidence in the life characteristics of the candidate subsystems. The second demonstration, however, will be the most important "proof." It involves extending the current subsystem-level testing to unmanned integrated testing and then a manned test of a prototype ECLSS in a closed-door chamber. The third will subject concepts potentially sensitive to zero-g to flight tests.

All three demonstrations being successful, final design can commence with good confidence.

F-4 describes the overall technology plan. An integrated ECLSS—the Technology Demonstrator—will be used in the manned test demonstration discussed above. Definition of subsystems for the Technology Demonstrator has begun. Concurrent with this are three separate technology activities. The first provides backup concepts in each important ECLSS area. The second covers technology potentially important to evolution of the space station. (Backup subsystems for the Technology Demonstrator will move to this activity if not required to support Demonstrator development.) The third, the basic R&T, leads to attractive options for the more distant future. This approach supports prime-contractor efforts early in the program. With proper coordination, the integrated ECLSS manned test bed can be used to generate development data for the prime contractor.

SPACE STATION TECHNOLOGY

SYSTEMS AND OPERATIONS

Living with Complexity and Growth

By W. RAY HOOK
NASA Langley Research Center

For the space station, nine working groups will oversee most of the research and the development of technology needed in nine separate disciplines. The complexity of the space station and its interactions with other space and ground systems calls for a tenth group to check on how the technology works together.

The space station will be supported by the Space Shuttle and a ground operations group with the Tracking Data Relay Satellite System tying the three together. The space station will host other spacecraft (F-1A) such as orbital-transfer vehicles, science and application free flyers and platforms, and teleoperator maneuvering systems. The crew also will carry out an impressive array of experimental and operational functions. Since the space station will likely be added to (F-1B) and old portions updated for at least 10 years after it is first put into orbit, careful attention must be given to the interfaces between elements of the station to prevent costly development and operational work-arounds later.

Complexity of the space station interfaces, need for evolutionary design, and for low development and operational costs are main concerns.

Growth in size and exchanging new technology subsystems for old ones can be made easier by developing computer emulation of the interfaces. Growth hardware can then be checked for compatibility before it is launched into orbit. It will be examined not only for form, fit, and function, but also to avoid unacceptable interactions with the complete space station. In the past, systems-level verification has been done using the actual flight system before launch. The same cannot be done for the space station, for it will grow on orbit.

W. RAY HOOK, (M), directs NASA-Langley's system analyses of large space antennas and permanently manned orbiting space stations. Earlier he contributed to systems studies of Skylab and Spacelab. Hook is a member of the AIAA Space Systems TC.

New-technology replacement subsystems may perform required functions in a radically different way. The interfaces must transmit whatever functions are necessary, independent of the technology incorporated into a subsystem. This approach to interface design has been called "technological transparency," which may be ensured by minimizing subsystem interactions through the use of a high degree of hardware modularity and a corresponding distributed data system.

The working group has the job of conducting systems analysis, interaction, and sensitivity studies across disciplines and architectural options. It will depend on computer-aided design and analysis.

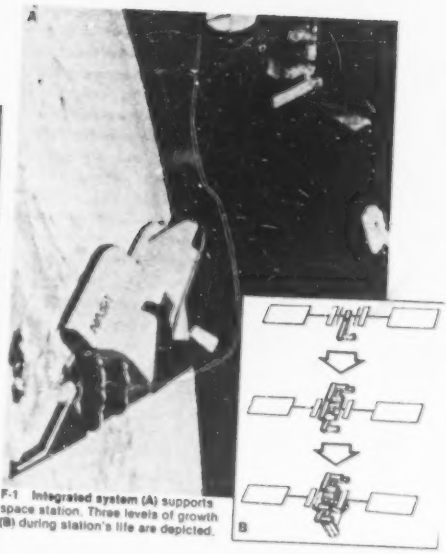
New technology is necessary for deployment, assembly, checkout, and operation of the original station, and deployment, mating, and checkout of modules sent up later. The long-range goal is to develop standardized payload checkout and operation with a minimum of ground crew involvement.

Assessment of the needs for and the benefits from autonomous operations must be evaluated broadly—across the space station system. The results of this assessment will be periodically fed to the other discipline working groups to assist their selecting technology goals that can significantly reduce costs. Efforts have begun to develop generic fault detection, isolation, and correction techniques that could simplify on-orbit operations, maintenance, and repair. Engineering assessment methods have to be worked out for making cost-effectiveness trade studies between reliability—gained through such measures as high-quality parts, or extensive screening and testing—ease of maintenance, and design for fault isolation and correction to obtain the lowest overall life-cycle costs.

Guidelines and standards for checkout, repair, servicing, and deployment of spacecraft from the space station by both EVA and teleoperators will be developed to identify technology gaps. Construction, erection, and assembly operations will be studied to evaluate the degree of automation desired and the types of equipment required. The technologies necessary for advanced manipulators, teleoperators, and robots will be defined. The goal is to capitalize on man's ability on orbit and to maximize his effectiveness in operating machines.

The working group is also responsible for a variety of tasks that do not relate directly to the disciplines of the other working groups. The tasks include alternative rescue and escape strategies, integrated hydrogen-oxygen system analysis, and computer-aided design and analysis application to systems trades.

Alternate rescue and escape strategies range in complexity from provision for safe havens on board the space station to remote space-orbital shelter or orbit-based rescue, to reentry escape or ground-based rescue using the Shuttle. Economics does not allow keeping a Shuttle Orbiter at the space station. This will be a significant change from the practice of keeping an Earth-return vehicle on station at Skylab and the USSR Salyut. This study will develop crew safety philosophy and criteria, assess potential threats to crew safety suggested by mission scenarios and associated station architectures, and evaluate the effectiveness of the various escape and rescue strategies to meet the desired criteria at reasonable cost.



F-1 Integrated system (A) supports space station. Three levels of growth (B) during station's life are depicted.

An integrated hydrogen-oxygen system promises the greatest reduction in resupply costs of any single development. Scavenging excess fuel from the Shuttle's internal and external tanks and using leftover Shuttle payload for fluid tankage could supply hydrogen and oxygen for propellants, fuel cells, and life support. This approach could reduce resupply and simplify fluid management. Advances in cryogenic fluid management and storage technology are the keys. They would also further the development of orbital-transfer vehicles, teleoperator maneuvering systems, and high-energy upper stages.

Additional technology would be needed for regenerative fuel cells, gaseous hydrogen/oxygen propulsion, and life-support systems. Fuel cells could be used as primary fuel cells only, as primary cells coupled with a photovoltaic array, or in a fuel cell/electrolyzer combined with a photovoltaic array. In the first, two arrangements the cells could

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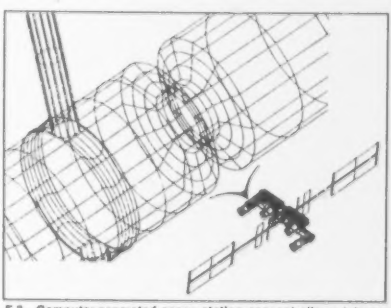
operate on propellant-grade hydrogen and oxygen scavenged from the Shuttle tanks. The regenerative system (F-2) would use water as the fuel for the electrolyzer. Water could be resupplied routinely by the Shuttle using excess payload capacity. In these concepts the fuel cell produces primary power and may be integrated with the life-support, thermal management, and propulsion systems for gains in cost savings and operational simplicity.

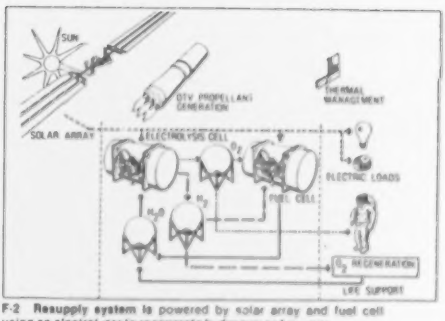
In the regenerative system, water output from the Environmental Control/Life Support System would be electrolyzed to make oxygen to go back into the life support system. The primary cell would convert oxygen and hydrogen into water for use in the thermal management system and as energy for the space station electric loads. Similarly, water could be delivered to orbit to be turned into hydrogen and oxygen for space-station-based, orbital-transfer vehicles. A new technology refrigeration and liquefaction system would be required to convert the gaseous fluids to the cryogenic state.

The discipline working groups have identified a long list of technology that needs to be developed. The next step will be to better quantify the payoffs from individual technology advances, understand the interactions of advanced technologies across disciplines and subsystems, and better define how they affect space station growth. Then priorities can be established.

A tool for setting these priorities will be the computer-aided design and analysis system called Interactive Design and Evaluation of Advanced Spacecraft (IDEAS) under development by NASA-OAST at Langley Research Center. The system integrates conceptual design and analysis software for large orbital spacecraft. Most computer codes for multidisciplinary analysis of large spacecraft had been collections of long-running, single-discipline,



F-3 Computer-generated space station concept allows interaction between program modules to design complete system.



F-2 Resupply system is powered by solar array and fuel cell using an electrolyzer to regenerate hydrogen and oxygen.

highly generalized codes that did not have the breadth needed to perform complete parametric tradeoffs of the total spacecraft, its supporting subsystems, and the on-orbit operational environment. With the new system engineers will be able to rapidly evaluate system concepts and technology needs for future large spacecraft more cost-effectively with less labor. The system consists of about 40 technical modules, efficient executive and data/file management software, and interactive graphics display programs. Technical modules include structural synthesizers and finite element modules; spacecraft dynamics and control system analysis; large-area drag, gravity gradient, and solar pressure environmental loading algorithms; structural element design; subsystem design and data base; habitable module support systems; operational analysis; and performance, cost, and reliability algorithms. The automated computer-aided design and analysis system allows interaction between modules and is used to create a complete system design (F-3) by putting in mission requirements and specified subsystem characteristics. The design is rapidly synthesized and evaluated, and performance characteristics are determined.

With the system, competing space station and mission designs can be rapidly evaluated, performance/cost tradeoffs made, technology sensitivity analyses carried out, and competitive technologies evaluated. These evaluations can maximize the return from the technology investment.

The success of a new space station will not be measured until many years after the station has gone on orbit. A primary measure of its success will be the degree to which the station has become a major element in a fully integrated space system. Focusing early on an integrated systems and operations design will help ensure this success.

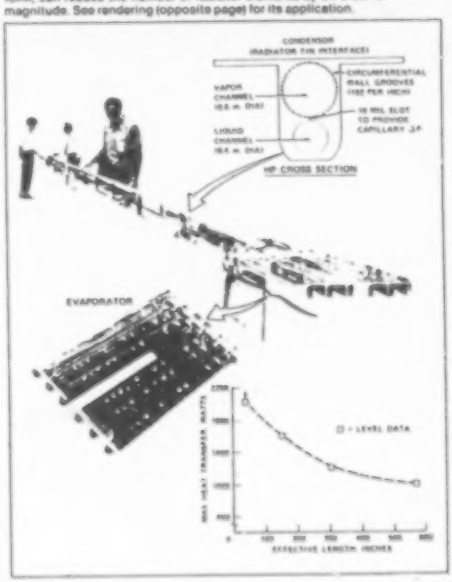
SPACE STATION TECHNOLOGY

THERMAL CONTROL

Heat Buses Will Operate Like a Public Utility

By W.E. ELLIS and J.G. RANKIN
NASA Johnson Space Center

This 2 kW monogroove heat pipe, already tested in prototype form, can reduce the number of radiator elements by an order of magnitude. See rendering (opposite page) for its application.



Multi-year mission duration, large quantities of waste heat to be dissipated, and the anticipated large variety of payloads and missions all will be major drivers in the design of space-station thermal control. The space station especially must be able to handle widely varying heat loads, sites of heat sources being changed by the crew as dictated by mission objectives, and, while continuously operative, evolutionary growth.

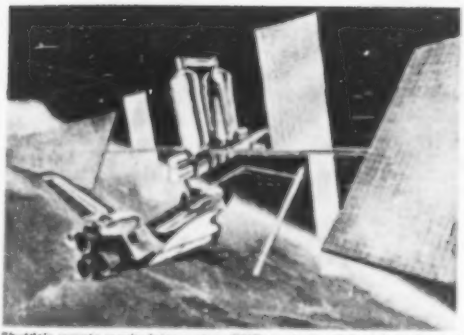
Active thermal control requires long-life heat rejection, highly versatile thermal transport, and efficient system integration.

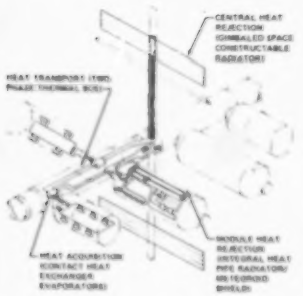
Heat rejection focuses on the requirements for final transfer of waste heat from the spacecraft to the ambient environment by radiation. Any concept for a large manned space station will need large deployed radiators for heat rejection. By a significant margin, the radiator will be the largest and most exposed portion of the space-station thermal system. Improvements in radiator size, complexity, and efficiency will be mandatory to gain the needed performance.

Transport requirements encompass the collection and movement of thermal energy from the space station's heat sources to the radiator heat sink at required temperature levels. Current thermal subsystems require precise ordering of equipment within the thermal-transport circuit to maintain temperature control (i.e., equipment requiring cold temperatures must precede in the circuit equipment that can tolerate higher temperatures). Modular growth of the space station will require it to accept multiple heat loads of various magnitudes, heat-flux densities, and locations without causing adverse interactions. That is, the station will need a highly versatile thermal "utility" or bus system analogous to a municipal public utility. Changes in location or load of individual subsystems and payloads must minimally affect the utility's ability to serve the remaining heat loads.

Current thermal systems make large use of electrical heaters and require much crew involvement to

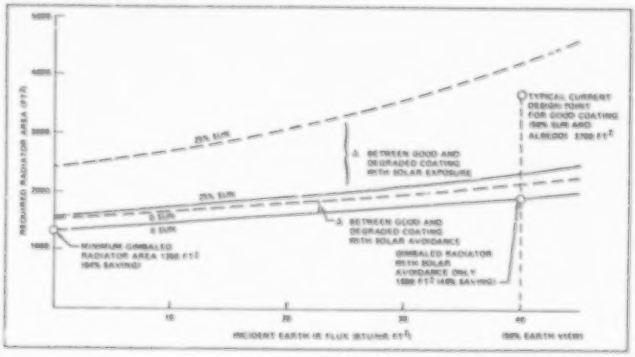
W.E. ELLIS, far left, directs the Systems Engineering Br. of the Crew Systems Div. at NASA Johnson. He has led NASA's in-house advanced thermal technology development program for the last 10 years, particularly heat pipe applications to spacecraft. J.G. RANKIN, senior thermal control system project engineer at NASA Johnson, joined NASA in 1971 to work on the Shuttle active thermal control system and EVA mobility unit. Previously, with Vought, he had a hand in thermal control of Apollo and Skylab.




CENTRAL HEAT REJECTION (GIMBALED SPACE CONSTRUCTABLE RADIATOR)
HEAT TRANSPORT (TWO-PHASE THERMAL BUS)
MODULE HEAT REJECTION (INTEGRAL HEAT PIPE RADIATOR/ OR TEORDID SHIELD)
HEAT ACQUISITION (CONTACT HEAT EXCHANGER EVAPORATOR)

Shuttle's remote manipulator system (RMS) emplaces 55-ft modular heat pipe in space-station radiator. Such a space-constructable radiator forms a principal element of the advocated active-thermal-control system diagrammed here.

F-1 ADVANTAGE OF GIMBALED RADIATOR
Radiator-area sensitivity to external environment for 50-kW heat rejection at average 80 F temperature.


REQUIRED RADIATOR AREA (FT²)
25% SUN
0 SUN
Δ BETWEEN GOOD AND DEGRADED COATING WITH SOLAR EXPOSURE
Δ BETWEEN GOOD AND DEGRADED COATING WITH SOLAR AVOIDANCE
TYPICAL CURRENT DESIGN POINT FOR GOOD COATING (50% SUN AND ALBEDO)
MINIMUM GIMBALED RADIATOR AREA
GIMBALED RADIATOR WITH SOLAR AVOIDANCE ONLY
INCIDENT EARTH IR FLUX (BTU/HR-FT²)
(50% EARTH VIEW)

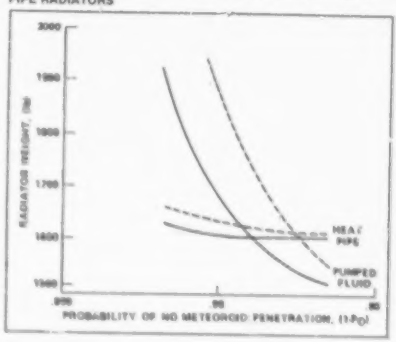
change the system's operating configuration as power profiles and heat loads change and system failures occur. The space-station thermal system must make judicious use of waste heat (minimize or eliminate electrical heaters) and minimize crew involvement by using an automated thermal utility system. Operational life and costs will be key issues in design.

In a decentralized thermal system, each module of a space station would collect and reject all of the waste heat generated with no module interconnects necessary. Each module would have complete flexibility in the selection of its control temperature and in how its heat gets rejected. It would be possible for modules to use different working fluids and devices. However, the decentralized approach would not allow waste heat from one module to be used by another. Also, since each module rejects its own heat, it would need its own radiator and thus impose its own orientation and location restraints on the overall vehicle. Since several modules may require radiator deployment to achieve heat rejection, overall thermal complexity and weight of the system would tend to be high.

In contrast, a centralized thermal system would allow maximum use of waste heat from one module by another. It would minimize the size, and thus the cost, of the thermal system. Because the system could take advantage of the "peaks and valleys" of the module heat loads, it could be sized for an average vehicle heat load and thus be significantly smaller overall than a decentralized system. A centralized system also allows efficient radiator design and positioning "out of the way."

In the centralized system heat must be transported across module boundaries. Several methods of doing this have been investigated, such as direct fluid interface through fluid disconnects, typical compact heat exchangers with connectors, and contact heat exchangers. The latter two would not require intermixing of module heat-transport fluids. The contact heat exchanger has the additional advantage of entirely eliminating fluid connections, thus improving reliability and providing more flexibility in thermal-control design for the individual modules. Also, the contact heat exchanger simplifies adding new modules to the station during build-up and routine equipment installation. Its pri-

F-2 METEOROID SENSITIVITY OF PUMPED FLUID AND HEAT PIPE RADIATORS



mary disadvantage is a somewhat higher temperature drop across the interface.

All space-station concepts envisioned to date require large deployed radiators to reject waste heat. It is necessary to minimize the size of the radiators not only to hold down weight and cost, but also to simplify design and operations. Smaller radiators simplify launch and construction, vehicle attitude control and stability, maintenance, payload space-sensor viewing, resupply-vehicle docking, and micrometeoroid protection.

In general, for minimizing size, radiator panels should travel edge-to-Sun as much as possible. F-1 illustrates radiator-area sensitivity to the external thermal environment. Gimbaled continuously away from solar flux and Earth flux as much as possible, the radiator can have an area as much as 60% less than one of fixed orientation. The figure also illustrates another advantage of a gimbaled radiator; not being directly exposed to the Sun, its thermal coating would degrade less.

High reliability for long-duration missions can be achieved with a Shuttle-type (separate-tube) radiator if it is adequately shielded, but the system would be heavy and complex because of redundant plumbing, pumping, and valving. To handle 100 kW of heat rejection an existing Shuttle-type fluid radiator system would require over 19,000 ft of tubing consisting of over 1500 individual pumped fluid tubes, over 50 fluid manifolds, over 75 isolation valves, fluid disconnects, and fluid swivels (or flex lines).

A radiator using multiple independent heat pipes offers an attractive means to eliminate most single-point failures. Loss of a single heat pipe would not be catastrophic. The heat-pipe radiator would thus need much less meteoroid protection. Prototype heat-pipe panels have been designed, built, and tested. F-2 compares the weight of conventional fluid-type radiators and heat-pipe radiators for a long-life space station. The implications for micrometeoroid protection are clear. Heat pipes can also greatly decrease system complexity. A single heat pipe can passively reject as much as 2 kW of heat. Thus as few as 50 could handle a 100-kW space station.

A high-capacity monogroove heat pipe (opening illustration) has been developed to simplify space radiators. It separates the heat-transport and heat-transfer functions so that they can be optimized separately to transport 600,000-1,000,000 W-in. with high film coefficients. It combines the advantages of axial grooves, such as simple construction and large liquid and vapor areas, with the high heat-transfer coefficients of circumferential wall grooves. (The basic monogroove design contains two large axial channels, one for vapor and one for liquid. The small slot separating the channels creates a high capillary pressure difference that, coupled with the minimized flow resistance of the two separate channels, gives the high axial heat transport. High evaporation and condensation film coefficients are provided separately by circumferential grooves in the vapor channel walls.)

The space-station designer must decide to deploy or to construct the radiator space. A pumped-fluid radiator would probably require deployment, because of the complexity of making and insuring leak-tight fluid connections in orbit. A deployable radiator would simplify initial on-orbit buildup, but at significant system complexity, weight, and cost. The deployment mechanism will be inherently complex, requiring drive motors, fluid swivels, and flex hoses; these would increase radiator weight by 25-50%. Heat-pipe radiators readily lend themselves to on-orbit construction since they are made up of several independent, closed elements. The leak of a single heat pipe during construction would not significantly reduce overall system performance. Construction in space would require on-orbit crew time using the Shuttle's remote manipulator system (RMS), but would decrease overall radiator system complexity, weight, and cost. Perhaps of overriding importance for the life requirements of the space station, space construction would be inherently maintainable on orbit.

A space-constructible radiator that fully meets the challenges could use the large (~2-kW) independent heat-pipe elements and a centralized heat-transport circuit. Any radiator area would be formed by putting together the required number of heat transfer elements.

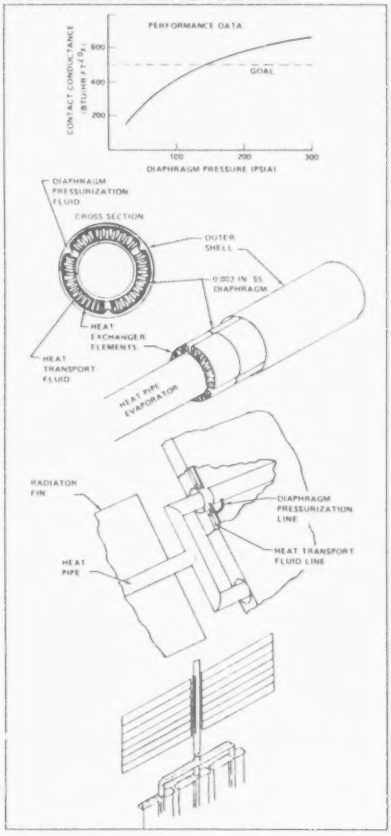
The space-constructible heat-pipe radiator, illustrated in the rendering near the beginning of this article, would reduce the number of radiator elements by an order of magnitude (e.g., 50 heat pipes vs. 1500 fluid tubes for a typical 100-kW system). The reasonable size and relatively small number of radiator elements make RMS use practical. Individual heat-pipe elements could likewise easily be replaced or upgraded. Launch weight and volume would be minimized because the radiator elements could be compactly stowed.

The requirement to transfer up to 100 kW out of the heat-transport circuit and into the radiator system through a *contact* heat exchanger presents one of the major challenges for any type of thermal-management system. Interfaces must be attachable and detachable in a zero-*g* space environment using the RMS. That complicates the design of its elements. Heat transfer must have a low temperature drop. That necessitates intimate thermal contact across the joint. Bolted joints have been used both for ground and space applications, and interface materials such as indium foil and thermal grease have been used to aid heat transfer. But such joints would be very hard to assemble in space.

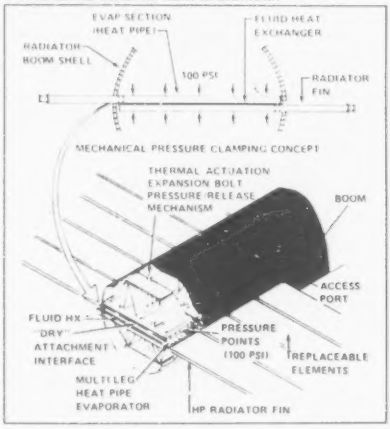
Two types of thermal-contact joints have been investigated as alternatives. Both rely upon the application of pressure to dry surfaces in intimate contact to provide the required heat transfer. In one (F-3) the RMS would insert the evaporator of the heat-pipe panel into the heat exchanger. Gas or hydraulic pressure against a diaphragm would force contact between the surface of the heat pipe and the fluid heat exchanger. Heat-transfer coefficients as high as 500 Btu/hr-ft^2 have been measured for joint pressures of 150 psi (see F-4). The disadvantage of this concept involves the added complexity of components associated with the gas or hydraulic pressurization system.

F-4 illustrates a second approach, using a flat contact heat exchanger. Thermal-expansion bolts and a truss assembly apply 100-psi pressure to the interface to distribute the load over the contact surface. A prototype heat exchanger of this type is be-

F-3 MECHANICAL CONTACT HEAT EXCHANGER



F-4 PRESSURE-CLAMPED HEAT EXCHANGER



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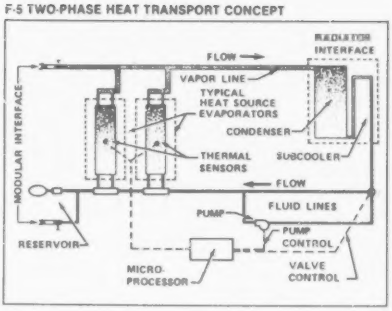
F-5 TWO-PHASE HEAT TRANSPORT CONCEPT



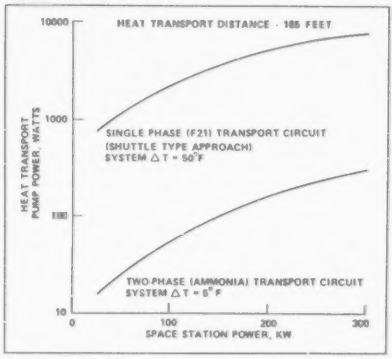
ing fabricated.

In previous manned spacecraft, pumped liquids have transported heat between sources and the radiator heat sink. These conventional loop systems use mechanical pumps to circulate Freon 21 or water. Pumped-loop technology has been found to be fairly reliable. However, when sized for a space station, they bring severe pump-power penalties and operational constraints. Pump-power penalties for a 100-150-kW space station would be on the order of 3-5 kW. This would not only be a very significant energy consumer, but also would require extremely large and costly space-qualified pumps to be developed and fabricated. The large pumps would be major sources of noise and vibration. Furthermore, their periodic maintenance, refurbishment, or replacement would be a continuing drain on operating costs and crew time.

Operational constraints of the pumped-fluid system would reflect the large temperature differentials around the fluid circuit. (The Shuttle Freon 21 loop operates with a temperature differential of about 50 F, from 40 to 90 F, during its path around the heat-transport circuit.) Varying and constantly increasing heat-transport fluid temperature would require equipment to be placed in the circuit at the *precise* place where fluid temperature could handle the necessary cooling. Thus, equipment must either be placed in proper order or fluid lines must often double back on themselves to place equipment in proper order relative to the fluid loop. This is an acceptable burden on small spacecraft and is tolerable even on large spacecraft like the Orbiter, which has fixed heat loads. However, even on the Shuttle, the liquid circuit places undesirable limits on payload thermal support. For a large and evolving space station, needing flexibility in place and magnitude of heat loads, a pumped-liquid system will impose severe operational constraints—perhaps even severe enough to prohibit certain missions.

A space-station system has been conceived to solve such problems—a two-phase heat-transport circuit (F-5) that moves heat into or out of the loop by evaporation or condensation of a working fluid (e.g., ammonia). The prime mover for the fluid is a small pump in the liquid portion of the loop. Evaporative heat exchangers remove the heat load from individual subsystems or payloads. The vapor from the heat exchanger is fed through a vapor-return line to the radiator interface heat exchanger where it is condensed and slightly subcooled. The liquid that comes from the radiator heat exchanger is then circulated back to the heat loads by the pump. Because heat transport is determined by the heat of vaporization (e.g., ammonia, 589 Btu/lb/°F) rather than the heat capacity of Freon 21 (0.24 Btu/lb/°F), the pump flow requirements are at least 50 times less for this system than they would be for a Freon 21 fluid-circulation system. Many of the components, particulary the pump, can thus be much smaller.

F-6 POWER REQUIREMENTS FOR SINGLE- VS. TWO-PHASE HEAT TRANSPORT CIRCUIT



F-6 illustrates the overwhelming advantage in pump power of a two-phase heat transport circuit over a Shuttle-type pumped-liquid circuit: for a 100-150-kW space station, less than 100 W compared to 3-5 kW for a pumped-liquid system. Long-life space-qualified pumps of 100 W or less are readily available.

Because the evaporation and condensation processes are essentially isothermal, the two-phase loop provides a uniform thermal-control bus temperature for space-station subsystems, experimental

equipment, and payloads. It eliminates the need for sequencing of heat-generating equipment. It broadly serves the overall needs of space-station modularity, operational flexibility, and evolutionary growth.

Several two-phase-circuit hardware test programs have proved the feasibility of the thermal-bus concept. A capillary-pumped two-phase loop (CPL), developed in the mid-Sixties, transfers significant quantities of heat with little temperature drop and no external pumping. It consists basically of a wick evaporator and continuous loop. Recently, a new prototype was developed and tested with Freon 11 on a 33-ft-long CPL. It demonstrated a capacity of 400 W (158,000 W-in.). Subsequent tests with ammonia demonstrated a capacity of 1,400 W (554,000 W-in.) with only two evaporators. Because the evaporators are in parallel, much higher capacities can be reasonably projected.

Another thermal-bus concept—a pumped, two-phase series loop—has also been tested. It uses a closed pumped-fluid loop serially interfaced with several evaporators.

An alternative would be a pumped, two-phase parallel circuit, and this also is under experimental investigation. Its evaporator, condenser, and vapor and liquid return-lines can be sized independently to achieve optimum tradeoff between pressure drops, heat-transfer performance, volume, and weight.

One additional approach to the thermal bus should be mentioned—the capillary-pumped plate. Two different capillary plates are being investigated. One relies on wick structure for pumping; the other, on machined grooves in the plate.

Out of these many considerations has come a strong candidate for the thermal management system. Illustrated at the beginning of the article, it optimizes system weight, power consumption, growth capability, operational feasibility, maintainability, and cost. The two major elements of the system are the heat-transport and heat-rejection subsystems. The pumped two-phase thermal bus operates at a near-constant temperature, independent of location in the circuit, for payload and subsystem heating or cooling, while requiring less than a tenth of the electrical power of a comparable single-phase pumped-liquid system. Its space-constructible heat-pipe radiator will allow any size of radiator system to be erected or maintained at any time during the space station's evolution by simply combining the required number of identical, independent heat-pipe radiator modules. The same basic high-capacity heat pipe would be used in a combination meteoroid-shield/radiator module design to minimize deployed radiator area.

SPACE STATION TECHNOLOGY

HUMAN CAPABILITIES

Long Residence an Uncharted Field

By ALAN CHAMBERS
NASA Ames Research Center

Skylab and Soviet space-station work confirmed that man can live and work in space for several months. Both demonstrated man's ability to overcome unexpected difficulties. Without the extravehicular repair of a damaged solar array and placement of a sunshade, the entire Skylab program would have failed.

We have seen the value of the astronaut as pilot, scientific observer, systems manager, and engineering technician. The Shuttle program continues to exploit a crew in these roles.

One can predict, however, that the change from the intermittent flights of the past to permanent residence in space will bring problems. Once in operation, the space station will not be seen as a "one-of-a-kind" space spectacular, and the astronaut will lose the aura of hero or novelty. The extensive training which has characterized earlier programs will diminish under the pressure of increased launch rates. And, as their roles expand, crews operating in space will come from a far more heterogeneous group socially, educationally, physiologically, and psychologically.

Moreover, advanced computer technology with high speed, high-capacity onboard data processing will change the relations of ground and space operators. It will bring about changes in command and control strategy and psychology, requiring careful integration of people and technologies.

Living and working in the space station indeed requires fresh thought, from questions of food to robotics and Extra-Vehicular Activity (EVA).

Shuttle food provisions emphasize high-energy content, dense packaging, and unitary servings for quick access (F-1). Limitations in preservation technology cut out many foods and processes such as

ALAN B. CHAMBERS, chief of the Man-Vehicle Systems Research Div. at NASA-Ames, has worked on the problems of man in space, particularly environmental control, for 15 years. He has served on the Air Force Science Advisory Board since 1960.

freeze drying and reconstitution significantly alter others. But that deficiency will change as people in space press for better, more normal meals. Improved means of preservation, bulk storage, and reconstitution will probably precede even limited onboard production of foodstuffs, but technology to grow food in space will be a long-term goal. Packaging and onboard preparation, including means to reduce waste and prevent spoilage, need near-term improvement. A better food technology should serve the space-station occupants. By and large, it has not been created.

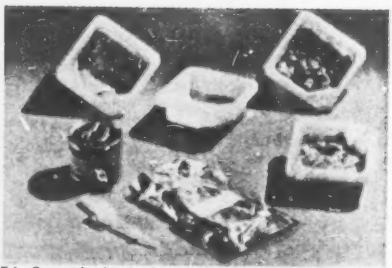
Another concern is contaminants. Space missions involve elaborate precautions to prevent crew exposure to pathogens and equipment-related toxins, vapors, and particulates. New considerations arise with respect to permanently manned vehicles. Periodic rotation of personnel and onboard experiments involving animals and other life, will expose stabilized, susceptible crew members to new pathogens. All manner of equipment and operations (manufacturing, vehicle maneuvering, maintenance and repair, and waste disposal) also will increase exposure to contaminants. Decontamination, containment, and prevention technologies are yet to be developed.

A permanent station will need new, more comprehensive health maintenance procedures and provision for care of sick and injured crew members. Our assessment of medical risk factors indicates that research and technology programs should be started in numerous areas. It is necessary to define differences between the physiologic normal values on Earth and in space, identify effective zero-gravity therapeutic methods, develop medical equipment, test these concepts in space, and establish design criteria for space-station medical facilities.

Several other aspects of the physical environment will affect the long-term habitability of the space station. The vibroacoustic environment, for example, will directly affect the comfort and performance of the crew.

On Earth, much low-frequency noise goes through the "walls" to the outside atmosphere. In space, with the absence of this energy-absorbing atmosphere, the acoustic energy is reflected and may increase the interior background noise by 12 dB or more. Many of the onboard noise sources will be operated periodically, resulting in intermittent sound and vibration that could potentially be more distracting than continuous noise.

F-2 describes measured noise levels of Skylab and Shuttle and predicted levels for Spacelab equipment, along with Earth-based noise criteria. Measured levels have exceeded those acceptable for various activities, and have caused crew complaints, indicating need for better prediction and control. In some cases, adverse reactions to noise have developed despite fulfullment of design specifications. Shuttle and other orbital vehicles should incorporate improved design and control techniques that can be applied to the space station.



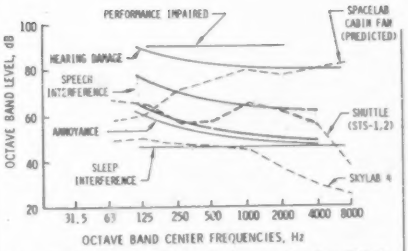
F-1 Current food technology, typified by packaged Space Shuttle fare, needs substantial development before space station crew members can hope for "normal" meals.

Many other habitability issues—architecture, personal hygiene and housekeeping, characteristics of the internal environment, crew work/rest cycles and off-duty activity—remain unresolved. Insights and answers may come from studying upcoming space operations. Although perhaps not concerned with hard technology, they may strongly affect performance in the space station.

As already indicated, two interacting concepts, automation and autonomy, will play an increasingly important role as space-station plans mature. In this context, automation means the degree to which space-station operations require manual control or intervention. Autonomy means the extent to which the space station becomes independent of ground support. A major challenge will be to determine how many ground-based functions can successfully migrate to the space station. Likewise, it should be understood how automation and autonomy affect the long-term performance and well-being of the space-station habitants. The interactions of displays, control, and data management need investigation. Existing specifications must be updated to include state-of-the-art technology and man-machine-oriented design models.

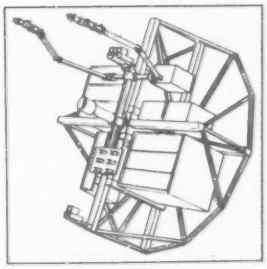
Teleoperators (F-3) no doubt will greatly improve man's overall ability to function in and from the space station. As teleoperator systems become more complex, however, control systems will have to be improved from what we have operating now. This will particularly be true for multi-task, multi-arm, and multi-operator systems. Modeling and simulation must stay abreast of advances in man-machine systems. An integrated program of hardware development, analysis, simulation, and evaluation should pace teleoperator technology readiness.

EVA unknowns compel more research. Several

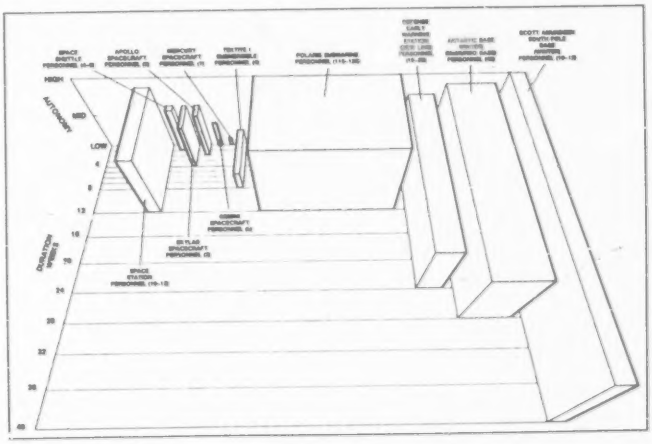


F-2 Space vehicle sound intensity (measured and predicted). "Amplification" of noise in a station in airless space could, unless attenuated, be injurious with long residence.

F-3 Remote orbital servicing system. Teleoperator technology aims at limiting space station's ground dependence.



F-4 Habitability analogs offer helpful guidelines for understanding crew reactions to extended periods of restriction in a space station.



technology development needs can be identified: restraint and attachment systems, communications, and information display to the EVA crew. A family of options must be developed to adequately cover worksite operations.

Other potential EVA requires attention. The duration and complexity of the space-station mission will require maintenance procedures for machine shop, repair shop, or depot. We know little about the effects of massive machinery upon a space-station environment (such as the pollution created by the residues of machine operation). Diagnostic operations, optics cleaning and refurbishing, lubrication and bonding will have to be addressed. Techniques are needed for overcoming the cumbersome space-suit glove. Dexterous tools and manipulators which approximate bare-hand work are needed for effective EVA.

The Shuttle gives us the opportunity to perform experiments that can promote good productivity from people and machines. Shuttle experiments, especially regarding food technology, virbroacoustic environment, EVA, and teleoperators can greatly clarify design decisions for the initial station.

The short missions planned for the Shuttle do not allow examination of all relevant issues, such as onboard management and effects of long-term isolation. On the other hand, we have extensive experience from nuclear submarines and antarctic bases (F-4), and this should help to plan operations and prevent problems.

The presence of a larger, more heterogeneous team in the space station will require technology beyond that necessary on previous missions. In order to meet this challenge, we will begin by taking full advantage of the Space Shuttle and lessons from the development and operation of these other, analogous systems to the space base.

SPACE STATION TECHNOLOGY

PROPULSION AND FLUID MANAGEMENT

Station Keeping Will Eat Energy on a New Scale

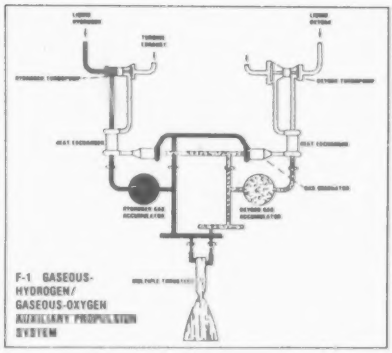
By DONALD A. PETRASH
NASA Lewis Research Center

In examining onboard propulsion and reduced-gravity fluid management, emphasis has been placed on identifying technologies that could be brought to a state of minimal development risk in the near term yet offer the potential for evolutionary growth consistent with future space-station propulsion requirements. We have reviewed needs for safety, integration of systems, and maintenance. The probable propellants for auxiliary propulsion are used in other systems and thus offer a resupply benefit and a benign rather than corrosive or toxic handling environment.

Auxiliary Propulsion: The auxiliary propulsion system provides attitude control, orbit change, acceleration control, and controlled de-orbit. The wide range of thrust required led to a mixed high/low propulsion system using chemical engines for all high-thrust applications and electrical engines for all low-thrust applications.

Considered state-of-the-art were the storable monopropellant and bipropellant pressure-fed propulsion systems now in use. Near-term technologies include a gaseous-oxygen/gaseous-hydrogen propulsion system, a resistojet, and improved diagnostics for both. Long-term technologies include inert-gas ion propulsion and electrothermal propulsion. Placed in a future (post-1990s) group and dropped from consideration, because they would require too much development, were solar thermal, nuclear, and arcjet rockets.

The anticipated total energy requirement for station keeping of large platforms in low Earth orbit (LEO) greatly exceeds the moderate requirements of present spacecraft. Higher specific impulse, moderate thrust, and high performance become increasingly important. A gaseous hydrogen/oxygen system will satisfy these requirements. As conceived, the system (F-1) draws liquid oxygen and liquid hydrogen from storage tanks, pumps them to the required system pressure, vaporizes the liquids, and stores the gaseous propellants in accumulators for feeding to the thrusters. A gas generator supplies the hot-gas working fluid for the propellant vaporizer and turbine drive of the pump. Overall performance will depend on the selected thrust level and propellant conditioning system; but specific impulse should fall between 375 and 400 sec. This system has a mature technology base.



F-1 GASEOUS-HYDROGEN/GASEOUS-OXYGEN AUXILIARY PROPULSION SYSTEM

The resistojet, an electrothermal device, uses a resistively heated energy exchanger to heat a gaseous propellant and then expand it through a nozzle. It requires externally produced electrical power. Thrust is low—about 0.2 N of thrust per kilowatt. Depending on propellant selection, specific impulse can range from 300 to 600 sec using near-term, low-risk technology. It can range up to 1000 sec with advanced technology. The resistojet can use various propellants, including storables such as hydrazine and ammonia, hydrogen, and those commonly associated with manned systems—water, carbon dioxide, and methane. The effluents in most cases are like the propellants, nonreactive and noncontaminating. Long-term ground and space tests have built a good data base on resistojets. (An operational communications satellite uses hydrazine resistojets.) Technology advances appear to entail very low risk and offer a high growth potential.

The need for both ground and on-orbit inspection and monitoring for useful life will require better engine diagnostics. The diagnostics must permit timely, cost-effective repair or replacement of

DONALD A. PETRASH, as chief of the Space Propulsion Div. at NASA-Lewis, heads research on H_2/O_2 upper stage and electric propulsion, for which Lewis is NASA's lead center. Earlier, he directed work on reducing aircraft engine emissions.

system components. The precise diagnostic requirements have yet to be determined, but they will call for technology development of sensors.

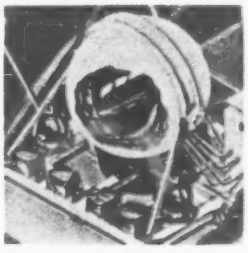
Inert-gas ion thrusters offer the highest performance of the proposed propulsion concepts. Through high performance, low thrust, and benign effluents, these engines offer cost, performance, and integration benefits for large space systems in high Earth orbits and free flyers associated with a LEO space station. High specific impulse means less mass and longer system life; that spells less spacecraft maintenance and resupply costs.

Fluid Management: The space station will store and supply a variety of fluids, including cryogens and refrigerants, to meet the needs of various subsystems. In the near term, fluid management will be dictated by the needs of the station's own operational subsystems. In the far term, it will probably be dominated by the desire to refuel space-based Orbit Transfer Vehicles (OTVs). As the station evolves, experiments, satellites, and OTV payloads may rely on it for periodic servicing and resupply of fluids.

Obviously, fluid-management subsystem requirements and characteristics cannot be fully defined until a reasonably firm mission scenario has been established and other space-station subsystems have been defined more clearly. It is possible, however, to see major options. A few questions bring them into focus.

Will a centralized storage and supply system be possible, or are the fluid requirements too diverse? Should resupply be by individual tank replacement, a logistics-module exchange, or transfer from a tanker via interconnecting lines? Where will the fluids come from?

Centralized fluid storage and supply that allows integration of space-station systems appears attractive if the variety of required fluids can be kept small. Adoption of centralized fluid management will simplify logistics. It will give the maximum fluid margin to meet contingencies—for instance, OTV propellants could be used in a fuel cell to provide emergency electrical power. Use of common fluids meeting the requirements of several systems adequately must be compared with the choice of a fluid to meet each system's requirements optimally. This will be the subject of much further study.



F-2 Experimental cryogenic fluid transfer unit would recover unused Shuttle propellants to fuel OTV.

For relatively small fluid quantities, the designer must consider the periodic replacement of individual fluid tanks and use of a logistics module for the complete fluid storage and supply subsystem. As the space station grows, it will be necessary to transfer fluids from the Shuttle Orbiter to the station, preferably by interconnecting lines. Fluid-replenishment options need to be compared on the basis of operational complexity, Earth-to-orbit transportation costs, availability of technology, and impact on evolution of the space station.

Liquid hydrogen and liquid oxygen will eventually be stored on the space station to support OTV operation. Options for making these fluids available need to be explored. Methods of recovering unused propellants from the Shuttle Orbiter and External Tank need evaluation to define Shuttle modifications and performance penalties. It will be necessary to compare the economics of dedicated Shuttle fluid-resupply missions, manifesting of Shuttle payloads to provide maximum use of Shuttle capability by using fluid tanks of different size, weight, and geometry, and the Earth-to-orbit transportation of water and hydrazine followed by on-orbit manufacture of propellants by electrolysis or catalytic reaction and liquefaction.

NASA has programs to develop the ability to store and supply cryogenic liquids on orbit and to resupply both noncryogenic and cryogenic liquid systems by liquid transfer from the Shuttle. F-2 depicts an experimental liquid-hydrogen transfer unit mounted on a Shuttle/Spacelab pallet. It will be used to establish operational techniques and design criteria.

We also see a need to develop—

—Leak-proof fluid couplings and leak-detection techniques to enable safe and contamination-free fluid interconnections and transfer.

—Fluid-quantity gauges that give accurate readings under weightlessness.

—Reusable and lightweight insulation for Shuttle tankage used to transport cryogenic liquids.

—Long-term orbital cryogenic-liquid storage facilities, possibly employing refrigeration and liquefaction systems.

In summary, several options for space-station auxiliary propulsion come within the state of the art, yet have growth potential demanded by the evolutionary nature of the project.

NASA has broad research and technology programs, including industry and university expertise and test facilities to produce and system test engineering-model hardware.

SPACE STATION TECHNOLOGY

STRUCTURES AND MECHANISMS

Streamlining for Fuel Economy

By MICHAEL F. CARD
NASA Langley Research Center

Being evolutionary, a space station will pose new problems in structural design. To make transportation costs as low as possible, station structure must be packaged efficiently in high-density modules taking the minimum of Shuttle volume fractions. Once in orbit, these elements must be deployed and assembled with a high degree of reliability. The inherent mechanical complexity of deployable structures must be traded against risking man in less complex erection activities. NASA and industrial R&D has shown the practicality of a crew erecting space structures (F-1).

In terms of architecture, a master plan must be created which exploits near-term hardware, yet can grow into a large complex. Basic issue: how to build into components the means for structural growth without compromising the initial system. F-2 depicts one possible solution—an initial configuration becoming part of a stiff closed cell in the final configuration. A stiff configuration is expected to reduce control-system problems.

How much should be invested initially to permit configuration growth? In terms of structural design, growth can be achieved by increasing initial design safety factors, introducing dynamic isolators to prevent loads from reaching the initial components, or preplanning refurbishment of initial structure with stronger elements. Intelligent design tradeoffs require definition of on-orbit loads (including docking and maneuvering) translated into load spectra for estimating fatigue life.

Structural components of the station will likely include tanks for long-duration fuel storage, manned capsules, large (possibly inflatable space-hardened) hangars, and large solar-array appendages. This ensemble will be drag-prone. Indeed, drag in low Earth orbit makes configuration a key parameter in system tradeoffs. F-3 gives estimates of Shuttle fuel deliveries required to keep large solar arrays or platforms in orbit for 20 years (Kyser, NASA 16620). A 150-kW Sun-pointing solar array in a 220-n.mi. orbit requires over 120,000 lb of fuel for 20-year life *without drag reduction*. A Sun-pointing array trimmed to a trailing attitude in shadow needs a lesser amount of fuel—something over 85,000 lb. A fixed trailing array (about twice the size of a Sun-pointing array) can cut fuel requirements to about one-fifth (26,000 lb) of the requirement for the untrimmed Sun-pointing array. The desire to reduce drag could make cable stiffening attractive.

MICHAEL F. CARD (AF), as chief of the Structures and Dynamics Division at NASA-Langley, oversees research on structural dynamics, solid mechanics, failure analysis, and composites. Card formerly chaired the AIAA Structures Technical Committee.

Structural joint's sockets slip together, then lock. F-1 shows joints being fitted into a space structure.

Because of the evolutionary nature of the space station, an archive of engineering design data will be needed to track configurations. F-4 suggests an integrated scheme for data bases, optimization analysis, and checking by critical tests. Data bases would be alterable at the analyst's or designer's convenience after stringent verification of proposed new data. The data base would be transferable to different computer operating systems, thus avoiding the need to convert computational codes.

Since full-scale "mated" static and dynamic tests will not be feasible as the station grows, designers will have to rely on analysis for qualification of

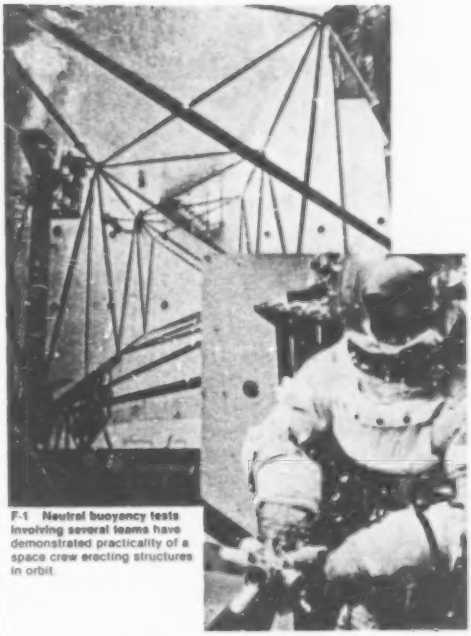
structures. F-5 describes an approach for obtaining a mathematical model that builds on pathfinder and structural models. Space-station complexity will pose a need for improvements in thermal, structural, and controls analyses—model simplifications, reduced computation times for heat-transfer calculations, methods of handling structural nonlinearities, (e.g., in solar arrays and articulated mechanisms), and improvements in modal synthesis and system identification.

F-5 shows need for four activities. A pathfinder model will be needed as soon as the basic configuration is known; it will be used to identify and resolve test and fundamental analysis issues. A replica-model program parallels full-scale hardware development. Unlike past programs, this model would continue as long as the space station grows. It will be the only source of mated vibration test data before orbital assembly. In parallel with this replica program component and element full-scale testing would be done. Finally, on-orbit vibration tests would check ground-test data and analyses and measure characteristics to be entered into the archival data base.

The long-life requirements of a space station will produce unique problems. Improvements in materials must be made to reduce contamination, slow materials degradation, and extend the life of coatings. F-6 describes a typical material degradation—change in solar absorptance of paints and reflective surfaces after several years exposure on a spacecraft in polar orbit (Winn, AFML-TR-78-79). Paints show continuous degradation whereas secondary reflective surfaces appear to stabilize after initial degradation (probably due to early contamination). More data on degradation is needed to characterize a broader range of materials, particulary composites. If deterioration cannot be prevented, simple methods of repair must be devised to restore desirable qualities.

The long-term integrity of structures must be preserved. Structures will need localized protection of critical elements against space debris and micrometeoroids. Redundant, fail-safe structures are likely to be employed with some form of on-board fault detection, especially for tankage. We may need to apply small forces to observe changes in characteristic "signatures" of on-orbit structures to test their integrity.

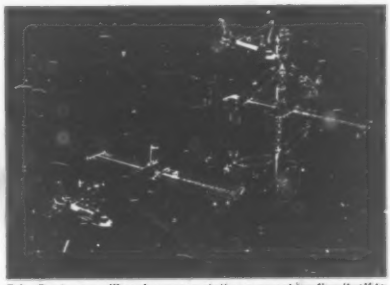
To minimize on-orbit maintenance, long-life lubrication systems and advanced sealing concepts must be developed. Solid-film lubricants and self-acting seals developed for engine applications need further research to determine their long-time integrity in applications such as docking latches and



F-1 Neutral buoyancy tests involving several teams have demonstrated practicality of a space crew erecting structures in orbit.

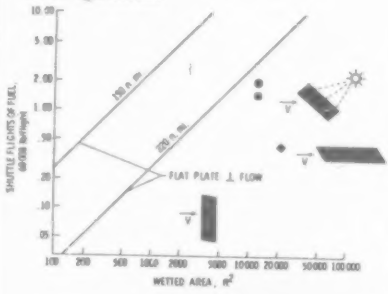
cryogenic pumps. Advances must be made in the reliability of mechanisms to avoid costly errors in detail design. Computer-aided kinematic analysis of real mechanical systems (including effects of tolerances, interference and flexibility) should improve design quality.

The spectacular growth of microprocessor technology suggests the development of "smart" mechanisms—programmable mechanisms having sensor feedback and capable of performing multiple functions, such as the "next generation" space-crane

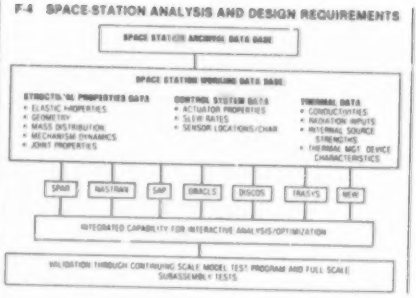


F-2 Designers will seek a space-station concept lending itself to evolution. Sketch indicates one approach—an initial, relatively simple power-cell platform becoming part of a stiff closed cell.

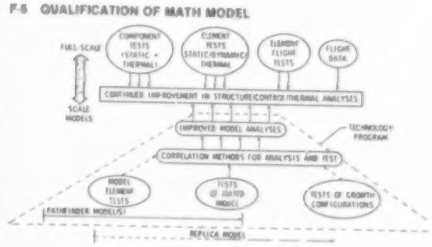
F-3 FUEL REQUIRED TO MAINTAIN A 20-YR ORBIT
Propulsion I_{sp} of 300 sec.



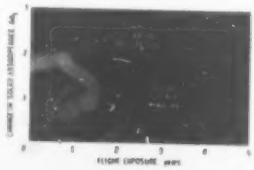
F-4 SPACE STATION ANALYSIS AND DESIGN REQUIREMENTS



F-5 QUALIFICATION OF MATH MODEL



F-6 DEGRADATION OF THERMAL-CONTROL COATINGS
Flight data from AFML-TR-78-99.



F-7 "Next-generation" space crane, along these lines, would use local sensors and actuators under programmed master control to take any desired configuration.

concept illustrated in F-7. Through a combination of local actuators and sensors, it can be programmed to retract and deploy and take a position in any desired configuration. Designers will likewise need reliable moving joints and latches with minimum deadband, low coefficient of expansion, long life, and high functional reliability.

To complement this development, a family of fluid couplings and electrical connectors needs to be developed and integrated with mechanical subsystems for module hookups, satellite maintenance, and refueling operations.

Finally, we will need new mechanisms for docking. Concepts are being investigated to reduce docking loads ("soft" docking with final velocities less than 0.1 ft/sec) and to berth inert payloads.

Technical concerns and a desire to develop experience in space station operations will likely lead to early experiments using the Shuttle. One logical candidate for a pathfinder experiment will be space construction. Problems in the dynamics and control of large flexible structures should also lead to pre-station flight experiments; basic issues are ability to predict and control vibrations on orbit, and to perform vibration testing, practical systems for orbit control, and usefulness of adaptive control.

NASA is studying practical approaches for performing low-cost experiments. A reusable pallet, called the Space Technology Experiments Pallet, would minimize integration cost and would allow reuse of expensive electronics. Plans so far would have the pallet used specifically for structures, structural-dynamic, and controls experiments that can be packaged compactly to allow convenient payload manifesting.

The development of a space station requires creative structural engineering to evolve a simple power module into a complex permanent base. The viability of this "infinite life" spacecraft will reflect the ingenuity of materials and structures engineers in solving durability and maintenance problems. ☐

SPACE CITY

2001 it's not.

by M. Mitchell Waldrop

Illustrations by Ron Miller

In 1869 the Atlantic Monthly published a whimsical and charming serial called The Brick Moon by the Boston clergyman Edward Everett Hale. Hale's creation was a utilitarian satellite made of brick that being visible from Earth, helped sailors navigate the seas. Its 37 occupants communicated with the ground by hopping in unison on the exterior of the satellite in Morse code. It was the first space station in science fiction.

Almost 100 years later there appeared the most famous space station in science fiction--the giant, rotating wheel in the film 2001. This one was a lot more plausible; the movie even featured a visit to the station by a winged shuttle craft.

The irony, however, is that for the last two years or

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so the National Aeronautics and Space Administration has been hard at work planning a *real* space station, and its plans are turning out to be a good deal closer in spirit to Hale's utilitarian mass of brick than to the more glamorous wheel. The political realities of the 1980s make it clear there will be no return to the glory days of the Apollo moon landings when space spectaculars were their own justification. If NASA wants a multibillion-dollar space station, and it's hard to see how the cost could be less, then the country had better get a few billion dollars' worth of use out of it.

NASA's station would not even resemble a wheel. In fact, since it will have to be pieced together out of modules ferried up one at a time by the space shuttle, it will look more like something a child would build with an Erector set. The station probably would not rotate; the astronauts' experience with Apollo and Skylab showed that centrifugal imitations of gravity are unnecessary. Nor would it soar very high; the shuttle is limited to orbits under 700 miles. But it would be a permanent base for humans in space, something that space pioneers and science fiction writers have dreamed of for generations.

In the course of planning the space station, NASA has asked scientists, businessmen, and other prospective tenants precisely how such a station might help them do their jobs. The question initially surprised a lot of people who were still getting used to the space shuttle. But once they had thought about it, they all had very definite ideas of what they would need.

In astronomy, for example, some of the most exciting advances in the last decade have come from orbiting instruments sensitive to X rays, gamma rays, ultraviolet light, and infrared light, all wavelengths of the electromagnetic spectrum that are screened out by Earth's atmosphere. With their detectors placed beyond this screen, astronomers have seen pulsars, supernovae, stars in the process of being born, and even, apparently, black holes. They are hungry to see more. With the space telescope, scheduled to be launched above the murk of Earth's atmosphere in 1986, they will be able to observe the planets in exquisite detail and study how faint, distant galaxies began forming in the aftermath of the Big Bang. Even more advanced instruments are being designed, some of which may be able to peer into the hearts of far-distant quasars and explain the source of their immense power.

These new telescopes could be flown on the shuttle or placed on separate satellites. But a panel of astronomers who recently studied the question for the National Academy of Sciences agreed that it would probably be more efficient to assemble many instruments on a single space platform where they could stay up indefinitely and share power, tracking, and communications hardware. The researchers stressed, however, that it should be an unmanned platform. They don't want their high-resolution telescopes shuddering every time somebody goes from the kitchen to the bathroom. On the other hand, the astronomers do want people nearby so they can visit regularly to change or repair equipment and replenish the liquid helium used to cool detectors.

Meanwhile, the people who work on exotic materials want just the opposite, a manned laboratory where they can run experiments in person in a comfortable, shirt-sleeves environment. The lab will not be glamorous: It will look like a tin can outside; inside it will resemble an airliner with its ceiling and walls covered with electronics and apparatus. But the lab will be serviceable, for space offers access to round-the-clock solar power and, more important, microgravity—*micro* instead of *zero* because there will always be a little bit of acceleration from atmospheric drag and any bumps and bangs that might shake the station.

Many enthusiasts have held out the promise of whole new industries in space. A weightless liquid, for example, need never touch the walls of its container, so researchers may be able to cool molten blobs of ultrapure silicon into semiconductor crystals in space without ever having to worry about contamination from the container. Nor is a weightless liquid roiled by convection currents, since there is little gravity to make the warmer

layers rise and the cooler ones fall. Thus, it may be possible to grow crystals that are larger and more perfect than any on Earth. By the same token scientists in space may be able to make new kinds of alloys from metals that separate like oil and water on Earth.

When the shuttle carries the European Space Agency's *Spacelab* aloft for its first flight this fall, at least half of its 77 experiments will be of that kind. "We're really looking forward to the station so we can get a lot of work done instead of one shot at a time," says Lowell K. Zoller, manager of the Engineering and Major Tests office at NASA's Marshall Space Flight Center in Huntsville, Alabama.

Spacelab, a joint venture of the European Space Agency and NASA, is scheduled to fly on the shuttle this fall. One American and one European scientist will conduct more than 70 experiments designed to answer such questions as how the sun affects Earth's weather and how plants know which way is up. Telescopes and sensors, on the pallet behind the lab, will be open to space.

In a separate endeavor, the aerospace company McDonnell-Douglas has teamed up with the Ortho Pharmaceutical Corporation, a subsidiary of Johnson & Johnson, to test a microgravity process for separating biological substances such as interferon and insulin-secreting beta cells. The process is an adaptation of a well-known laboratory technique called electrophoresis in which materials are suspended in a liquid and separated by an electric field. Without convection currents, the separation process in space is hundreds of times more efficient than it is on Earth. The partners have successfully tested their process and are now building a prototype manufacturing plant. The fully automated plant could be aboard the shuttle as soon as 1985. But they look to the space station for a full-time factory.

Ever since the space communications industry began booming in the 1960s, the trend has been to put more and bigger antennas on big-

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Evolution of the space station

Edward Everett Hale, best known as the author of the American classic *The Man Without a Country*, described the first manned space station in 1869 in a funny and fanciful short novel entitled *The Brick Moon*. Hale detailed plans to launch a globe-circling, 200-foot sphere that would serve as an aid to navigators at sea. His brick moon, supported by 13 internal spheres, was coated with a ceramic powder that would fuse as it flew through the atmosphere to provide a heat-resistant shell very similar to the ceramic nose cones and heat shields of today's spacecraft. Accidentally launched with 37 people and food and water aboard, the moon reached an altitude of 4,000 miles. Favored with gravity, an atmosphere, and abundant rainfall for their crops—Hale doesn't explain how that was possible—the inhabitants thrived and multiplied, as shown at bottom left in the illustration above. They even witnessed evolution of a sort. "Write to Darwin," they signaled to Earth, "that he is all right. We began with lichens and have come as far as palms and hemlocks."

Hermann Oberth, the German rocket pioneer, proposed a much more likely but much less charming scenario in his 1923 book, *The Rocket into Interplanetary Space*. Like a great many who followed him, Oberth overestimated the need for gravity. To create it, he proposed two manned rockets of about 400 tons each, as shown at top left in the painting above. Tethered together by a strong cable a few miles long, the rockets would rotate about each other creating an artificial gravity (an idea revived by NASA in the 1960s for a manned mission to Mars). Oberth also planned an enormous mirror to beam solar energy to Earth.

The first careful scientific description of a space station, which appeared in Hugo Gernsback's magazine *Science Wonder Stories* in 1929, was by an Austrian writing under the pseudonym of Hermann Noordung. Noordung detailed a station consisting of three separate spacecraft: a manned wheel, a solar power plant, and an observatory, all connected by air and power umbilical lines. The main unit was a torus 164 feet in diameter that spun on its axis to provide gravity.

In the late 1940s engineer H. E. Ross and artist engineer R. A. Smith of the British Interplanetary Society described an orbital base serviced by winged cargo rockets that would be a way station for a moon landing. The station would have a 200-foot solar reflector to generate power and a long boom to house radio transmitting apparatus.

The space station conceived by writer Fletcher Pratt and artist Jack Coggins in 1952 was a rare nonspinning, zero-gravity concept. They felt, rightly as it turned out, that gravity might not be a necessity in space, so they designed a station in the form of a hexagonal prism. Winged shuttles would ferry supplies from Earth needed to construct a small, multi-legged ship that would send explorers to the moon.

Probably the most esthetically pleasing and elegant of all space station designs was that of the great German rocket pioneer Wernher von Braun. Developed as part of a symposium on space exploration sponsored by the old *Collier's* magazine in the early 1950s, the design used only available technology and materials. the plan actually would have worked. The station, with its crew of 80 orbiting 1,075 miles above the Earth, was to be attended by a three-stage shuttle. A telescope would orbit nearby. The design was so influential that only recently did the United States and the Soviet Union abandon wheel-shaped stations. The idea survives today in the futuristic space colonies envisioned by Princeton physicist Gerard O'Neill.

With the possible exception of the Pratt-Coggins station, none of these pioneers anticipated what a *real* space station would look like. But that is a small point. For they were convinced of the need for one—and for the varied functions it could fulfill.

—Ron Miller

The first space station could be in orbit by the early 1990s.

(continued from page 63)
ger, more sophisticated satellites. The shuttle will be able to launch the larger antennae planned for the next decade or so, but eventually the satellites may outgrow the shuttle's payload bay. What the industry will need then is a transportation hub: a space station in low Earth orbit tethered to a separate platform with manipulator arms and other gear for assembling several payloads into "antenna farms." The hub would also offer refueling and docking facilities for an unmanned, reusable vehicle that would ferry the antennae up and back to the 22,300-mile geosynchronous orbit, where they will stay fixed over one spot on the equator.

This same transportation hub might also prove useful to planetary science. Researchers have had a decade of extraordinary successes, including the Viking Mars landers in 1976 and the later Voyager flybys of Jupiter and Saturn—followed by a more recent period of severe budgetary constraints. Things are looking up, however, and plans are now afoot to mount follow-up missions in the coming decade to the planets and to the comets and asteroids. If the scientists had access to orbiting facilities for assembly and refueling, they might also be able to mount much more complex missions—collecting and bringing back rock and soil samples from Mars, for example, or sending manned expeditions to nearby asteroids.

The orbiting transportation hub would also be essential for undertaking some of the ambitious projects proposed for the next century—satellites for beaming solar power to Earth, mining colonies on the moon and the asteroids, and eventually, perhaps, vast space colonies with farms, factories, and subdivisions housing tens of thousands of inhabitants.

The group that appears most reticent about the space station is the one that people tend to think would be first in line: the military. President Reagan's call for a space-based *Star Wars* missile defense system last spring only heightened the public's concern about the militarization of space. But even if someone could figure out how to build, say, a particle beam weapon or an X-ray laser—and many physicists have voiced severe doubts on that score—the Pentagon could hardly base them on a space station. Not only would the station be vulnerable to attack, but there would have to be dozens of such weapons in orbit in order to cover the Soviet launch sites around the clock.

The job of reconciling the varied requirements for a permanent base in space falls to John Hodge, an affable, silver-haired, English-born engineer who heads the space station task force at NASA headquarters. "What we're really talking about is a *system*," he says. "We'll have the space shuttle to get from the ground to low Earth orbit, a station in orbit, and a transport from the station to geosynchronous orbit." Because the users' demands are contradictory, he adds, "the buzz word these days is 'distributed architecture'"—NASA argot for a space station that is spread out like a swarm of bees.

The central complex of the swarm would contain a housing module for a rotating crew of four to 12 who would probably stay up for about three months at a time. The command module would contain basic life-support systems and communications gear. Nearby, floating free or tied to the central complex by Kevlar tethers, would be unmanned platforms for astronomy, Earth observation, and materials science. They would be serviced by astronauts or remotely piloted vehicles based at the central complex. Eventually, Hodge says, there might be two such clusters, one in equatorial orbit and one in polar orbit.

Hodge estimates that the system could cost from $7 billion to $9 billion but spaced out over many years. A space station does have one great advantage over a project like the Apollo moon landings or the space shuttle, he points out: It is modular. It can be built a piece at a time, which means that careful planning can keep the yearly cost down to something reasonable. If things move along at the rate that NASA would like, the first modules could be in orbit by the early 1990s.

First, however, NASA has to convince a very skeptical Washington. The budgetary climate these days is not conducive to building a multibillion-dollar space city. And worse, the agency is still trying to live down its image as a bunch of overly enthusiastic space cadets. The reputation is not entirely undeserved. In the late 1960s, as NASA's leaders were trying to fire people's imaginations for a dramatic new commitment in the post-Apollo era, they pushed hard for a gigantic orbital wheel housing 50 or 100 people full-time—the concept depicted in *2001*. The problem was no one could really explain what they wanted it for. Their naiveté fed a growing perception that space was just a stunt. We spent tens of billions of dollars on space Olympics to beat the Russians to the moon, and what were we getting out of it but moon rocks?

In the end, NASA got grudging permission from the Nixon administration to build one small piece of its vision: a reusable "logistics support vehicle" originally intended for ferrying cargo up to the space station and back. We know it now as the space shuttle.

The shuttle, unfortunately, turned out to be far more complex than NASA had imagined. Years of delays and cost overruns hurt the agency's credibility even more.

Thus when NASA administrator James M. Beggs revived the space station idea in 1981, the initial reaction—from some quarters at least—was scathing. "I am concerned that [the space station] will proceed regardless of the real need for such a program because NASA needs it more than the country needs it!" said Wisconsin's Senator William Proxmire.

Even the less vociferous critics wonder if the agency is obsessed with having a "manned" space station for its own sake. No one has any problems with NASA building unmanned platforms for astronomy and such. But what would the astronauts do up there that would justify the cost of maintaining them permanently? Presidential science advisor George A. Keyworth points out that we already have a kind of mobile space station—the European Space Agency's *Spacelab*, designed to ride in the shuttle payload bay like a camper in a pickup truck. "First let's capitalize on the investment we've already made," he says.

Under Beggs, however, NASA has been trying hard to own up to its previous mistakes and to build a solid base of support for the space station. Hodge, for one, is adamant about finding out what the users need before letting the engineers charge ahead with hardware designs. "To hell with the configurations. What are the requirements for the next 25 years?" he asks. He also argues that humans are needed in space—but not for the sake of glory. "Everybody agrees we should have a man in the loop somewhere. The question is whether to leave him on the ground operating things remotely or put him in space." He points out that the cost of maintaining people in space has to be balanced against the potentially high cost of building very smart, very reliable satellites and transmitting prodigious amounts of data up and down.

As for using the shuttle as a mobile space station, he says, it *sounds* good, but the shuttle was not built for that. It is limited in size and can only stay up for seven days. "It would be like trying to turn a truck into a hotel or a factory," he says.

Hodge's boss, NASA Associate Deputy Administrator Phillip E. Culbertson, worries about a failure of the imagination. "People's thinking is conditioned by what they know," he says. "Ask them what their needs are, and they usually describe what they already have. If you had tried to justify the development of television, the automobile, the computer, or the airplane on the basis of somebody's need at the time, you never would have built any of them. So those of us who work in high technology have to have faith that it will pay off."

Does that mean NASA should have a license to do anything it pleases? Hardly. NASA first has to demonstrate that the space station is more than a toy—that it has real utility now and that it opens new possibilities for the future. And in fairness the agency has gone a long way toward doing that.

But it does mean that there is no way to settle the question by analysis and study alone; NASA must persuade the political system, and especially the President, to take that leap of faith. Ronald Reagan is enthusiastic about space. But budgets are very tight. He will be making a decision on the station this fall. If he says yes, NASA will go ahead, and the first components of a space station could be in orbit by 1990 or 1991. If he says no, then the project will be effectively dead in this administration.

If it comes, says Hodge, the space station will be a utilitarian, workaday thing. No space Olympics here. By the very linkage of the words *space* and *utilitarian*, however, the station could prove far more important than all the heroics of Apollo. "Somebody once asked me how I defined success in this business," Hodge says. "And I said, 'Success is the day we have a mission and it doesn't appear in the newspapers.'" S

M. Mitchell Waldrop is a staff writer for Science.

TERRA-MAR

ALTERNATIVE STRATEGIES FOR SPACE STATION FINANCING

Submitted to:

Innovative Utilization
of the Space Station Program
Office of Space Science and Applications
National Aeronautics and Space Administration
Washington, D.C. 20546

Submitted by:

Donn C. Walklet
A. Tracy Heenan
Terra-Mar
2113 Landings Drive
Mountain View, California 94043
(415) 964-6900

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I. INTRODUCTION

The attributes of the proposed space station program are specifically oriented toward research activities. On the other hand, the ultimate goal of research is to develop technologies which can generate long term benefits for mankind. In our society, unless such technologies are deemed of national interest and thus are government funded, they must stand on their own in the marketplace. Therefore, the objectives of a United States space station should be based on "commercial" criteria; otherwise, such a project will not attract long term funding. The reality of this conclusion should be evident in these times when budgets will continue to be affected by lingering deficits.

At this point, there is encouraging evidence that some potential space station activities could be generating revenues from shuttle related projects within the decade. Specifically, the McDonnell Douglas and Johnson & Johnson electrophoresis prototype pharmaceutical processing experiments show significant promise. Other materials processing concepts as well as remote sensing, as documented by Terra-Mar's analysis for the TRW space station study, indicate substantial potential. Furthermore, the economics and thus the commercial feasibility of such projects will be improved by the operating efficiencies available with an ongoing space station program.

Thus, by the end of the decade, there may be several applications which will seek the services provided by or associated with a space station. That possibility can and should dictate the direction of current space station development. A future space station can generate a substantial proportion of its own funding on the basis of its commercial potential. This potential must be defined and documented in a format that will be well received by the investment community. In addition, each component of space station activity which has commercial potential must be matched with the appropriate financial vehicle available from the investment community. Wall Street is not a monolithic source of capital, and NASA must do its homework to appreciate the opportunities for private financing that a sophisticated investment banker, broker, or institution can provide.

This study will investigate the alternative methods available to NASA to finance the commercial component of its proposed space station. This analysis will be done in the context of Terra-Mar's previous research into the markets for remote sensing data and services and the financing concepts available for funding the next generation of orbiting remote sensing devices.

II. BACKGROUND

The space station as it is presently conceived may be quite different from its ultimate configuration in space. However, one thing is certain -- the space station will be an expensive undertaking. If NASA utilizes government financing (in other words, tax dollars), funding will be accomplished through the normal negotiations that are associated with obtaining money from Congress. On the other hand, if the space program takes on a commercial orientation, then it will be necessary to approach sources of private capital with a reasonable knowledge of their operating procedures and mechanisms. The latter are considerably different from those associated with Congressional funding.

The following analysis will describe in lay terms the process and procedures utilized by the investment community in funding desirable commercial enterprises. However, it should be recognized that investors are guided by one fundamental principle. They would like to get their money back in a reasonable amount of time with some compensation for the risks incurred and/or they would like to see sufficient growth in the fruits of their investment so they will continue to be secure in the knowledge that their dollars are well placed. Furthermore, they would like to see managers using their funds in an efficient and "lean" operation. Investors are generally extremely sensitive to time delays or deviations from proposed budgets. Although there may be some titillation and indeed ego fulfillment associated with seeing one's investment floating in orbit, when it comes down to making decisions, the "bottom line" will almost always be the dominant factor. In this situation, NASA will be given no more or less consideration than a bright-eyed entrepreneur walking in off the street with a new idea. In fact, considering that the entire pool of venture capital within the United States is approximately $5 billion, even enthusiastic pronouncements regarding the benefits of a $10 billion space station may not be well received by the investment community.

Given this situation, NASA will have to learn the language and procedures of the financial services community and perhaps assume a little humility along the way. The space station will be composed of many elements, some of which may fall into the commercial category and may be financed from private sources. However, as with Congress, it will be necessary for NASA officials to approach sources of capital knowing full well the requirements and the correct protocol. An awareness of the psychological as well as financial aspects of raising capital will be necessary.

III. ELEMENTS OF RISK: TECHNOLOGICAL, FINANCIAL, AND POLITICAL UNCERTAINTIES

The financial community has some basic guidelines by which it evaluates all potential investments. The perpetual question is -- what are the risks involved in financing the project? These risks could take the form of technical, financial, or political uncertainties. First, as far as a space station type investment is concerned, technical risks would be those associated with the operation of the facility as specified or as required to generate revenues.

Second, financial risks would be those associated with the required funding and revenues of the project in question. In other words, can the device be built within budget and on schedule and will it generate the projected revenues over its lifetime?

The third element of risk is in the political domain but indirectly relates to the first two elements. Specifically, will a government sponsored space station continue to maintain its priority in the government budget cycle through changes in administration and congressional constituencies? Therefore, if I am an investor in this project that depends on a government supported system, I want to know if I risk finding that space station turned off someday due to lack of interest or due to changes in priority among political constituencies in the government.

In general, structuring a financial deal is a process of juggling the elements of risk and reward over time. Whatever NASA can do to minimize the risks and maximize the returns over the shortest period of time will increase the level of interest on the part of the financial community. However, within the two extremes of a low risk, high return opportunity and a project with high risk and negligible return, where the bulk of investment situations lie, the mode of financing depends upon the "perceived" level of risk as compared to expected rate of return. Thus, an investor in treasury bills (usually considered a safe investment) expects a return only slightly greater than his passbook savings account, while an investor in a new company producing a new product for a new market expects a substantially larger return based on the anticipated level of risk associated with the project.

In addition to the factors of risk, reward, and time, there is the size of the investment to consider. Two projects with comparable risk-reward ratios will still be handled quite differently if one project requires $5 million and the other requires $500 million. At first glance, it is natural to assume that any project associated with a space station will be a "megabuck" proposition. On the other hand, to a great extent the use of a space station for manufacturing and materials processing, as an example, will

involve new and innovative concepts that may more rapidly emerge from a small group of entrepreneurial engineers rather than from a major corporation. Such small initiatives with such great potential will start with limited funding, low ground-based overhead, and lots of enthusiasm.

If NASA is truly committed to space commercialization in the future, its role may be to create a space processing "incubator" assuming it can relate to the venture capital elements of the financial community accordingly. At the same time, the "incubator" may cost several hundred million dollars to engineer and fabricate and thus NASA may also choose to deal with that segment of the financial community, (i.e., institutional lenders) that handles large investments (oil refineries and pipelines, for example) in an appropriate investment framework.

In bridging the range of investment possibilities, the remainder this report will concentrate on three major mechanisms for business financing and on variations and combinations of the three methods where appropriate. These financing methods include venture capital, R & D limited partnerships, and project financing. Each method is appropriate under different conditions and circumstances; however, considering the breadth of possibilities encompassed by these three techniques, there are relatively few viable business concepts that could not be financed by one alone or by a combination of the three.

IV. FINANCING METHODS

Venture Capital

Venture capital is a subset of equity financing -- in other words, financing involved with selling shares in the ownership of a company among individuals who may or may not be directly associated with the company. The majority of large companies are primarily funded through equity financing with their shares traded publicly either on one of the major stock exchanges or on the over-the-counter markets. The term venture capital is often associated with start-up companies or with companies that are small and have little or no operating history. Therefore by definition, there is greater risk involved with this kind of situation. Add the element of new technology and there is even more risk to be considered. On the other hand, the investors involved with venture capital are generally looking for higher return on their money and are willing to take calculated chances to achieve that objective.

The amount of money involved with most venture capital funding is small by NASA standards. The range is within $100,000 to $10,000,000 with the bulk of the financing occurring between $300,000 and $1,000,000. In this context, why should NASA be concerned with venture capital? As mentioned previously, new commercial technology is most frequently spawned in the venture capital environment. For example, the personal computer industry started in a garage in the Silicon Valley area of California in 1976 and now represents a $6 billion industry growing in excess of 50% annually. To a great extent, space commercialization will require the creation of product concepts which do not exist today. Large corporations will definitely be involved in this process, as are McDonnell Douglas and Johnson & Johnson in the current electrophoresis project on the shuttle. But based on recent past experience, it is more likely that new companies will respond to the challenge faster than large established companies. Facing competition from the upstarts, the large companies will then very rapidly respond to the challenge -- case in point, IBM's reponse to the personal computer market in 1981 after denying its existence in 1978.

Given a viable new product or service, the objective of the venture capitalist is to assist the new company through the risky early years of development and growth in anticipation of taking the company "public", the point when capital is raised through a public offering of stock. At this juncture, the value of the company is recognized in the price of the stock. Additionally, because the stock is widely traded at this point, the initial investors have significantly greater flexibility and latitude in "cashing in" their investment.

However, up to the point of going public, requirements for additional equity capital fall on the backs of the original venture capital group which must either insert additional funds to protect the viability of their initial investment or seek additional investment funds from other venture capital groups, thus diluting their share of the company. When such injections of capital are predictable and according to the business plan, then everyone is happy and content that the company is growing and progressing as planned. Also, if growth and potential profitability are ahead of schedule, the need for additional funds is not begrudged. It is the unexpected "negative cash flows" that make venture capital investors nervous. Outside influences of particular concern include unpredictable supplies of raw material and changing requirements for unique facilities and transportation, problems not unfamiliar to NASA.

In order to overcome this obstacle, NASA must be able to sign a contract which specifies the exact availability of facilities and the cost of those facilities to be used over a specified period of time. NASA, and thus the government, must be held liable for any delays that could affect commercial production schedules to the extent that short term sales revenues are lost and the viability of the company is jeopardized. Without such assurance, no sensible businessman would commit time or money to the space station program.

How can NASA best position its space station program for venture capital investment? Most immediately, by continuing the "joint endeavor" process while turning agreements around in weeks instead of months. In a similar manner, NASA must be prepared to provide space services rapidly and at a reasonable price to an investment community that cannot tolerate bureaucratic delays and that works on a very short, tight schedule with a limited budget. If a new venture calls for a 1990 space station facility at a $5 million annual lease rate, a "technical" or "budget" problem that delays the availability of that space station until 1992 and results in an annual lease rate of $10 million will not be tolerated.

Assuming that NASA can respond to this challenge, NASA must, in addition, sell its space station programs to entrepreneurs and venture capital sources in a manner responsive to their need for facilities. Will a new start company be interested in buying "up-front" a complete facilities module at $200 million? Unlikely. Will they rent or lease space starting at $200,000 per month if they can sell the resulting product for $400,000? There is a strong possibility. At this point, the pertinent questions are:

- can NASA fund the building of appropriate hardware and charge out its usage at an acceptable level so that it can recover its costs?

- if NASA cannot or chooses not to perform this function, are there other entities within the private sector who would willingly perform this function?

- if there are such "third party" opportunities, can NASA in turn respond to their needs?

The second and third questions above will be addressed later in this report. But an important point to make now is that all forms of commercial financing are tied together by common threads of self interest. Therefore, on a more earthly level, a new high technology company will require manufacturing facilities to do its R & D and to build its product. Consequently, the company leases office and laboratory space from a real estate investment company that in turn receives its financing from banks and insurance companies. Thus, NASA is confronted with not only the priorities of the venture capital community but also with how these priorities relate to other financial interests. Similarly, financial institutions involved with setting up limited partnerships and structuring project financing for the fabrication of space facilities must have commercial tenants with a viable application in mind. Indeed, a communications customer may walk in with contracts and commitments in hand. Yet, organizing and cultivating potential new venture concepts, and specifically their financial supporters, will be a fundamental requirement for stimulating the long term development of commercial space activities.

Research and Development Limited Partnerships

As a financial vehicle, the limited partnership has been around for many years. The concept centers on the utilization of funding from a group of investors, known as limited partners, and on the management group, composed of individuals or a corporation known as the general partner, all of whom are organized under specific legal and accounting guidelines. The primary objective of a limited partnership is to provide off balance sheet financing -- in other words, funding not affecting the credit status of the company -- while providing specific tax and income benefits to an otherwise unaffiliated group of investors. Specifically, the investors receive the immediate tax benefits associated with the purchase of hardware and equipment with the additional commitment to receive a specified percentage of revenues from the resulting project over a predetermined period of time. The company presumably does not need or want the tax benefits, avoids the use of debt financing or equity financing, and is not required to indefinitely share

the profits of a specific project or the long term prosperity of the company with the investors/limited partners.

In the past ten years, a variation of the standard limited partnership has evolved which provides specific benefits to those companies developing new high technology products. Known as the R & D limited partnership, it is designed to complement rather than replace conventional equity and bank financing. The R & D partnership is particularly beneficial in that it is designed to efficiently utilize available tax benefits to minimize an investor's after tax capital at risk and thus substantially boost the after tax returns. Furthermore, if the research project proves to be successful, the royalties may be taxed at the long term capital gain rates. Consequently, these tax benefits enable an investor to take financial risks which would otherwise be unacceptable to venture capital as well as conventional equity investors.

The benefits provided by the R & D partnership are based on three major elements of the tax code and related legal decisions. First, the Internal Revenue Code, Section 174, permits an electing taxpayer to currently deduct qualifying research expenditures rather than capitalize them as part of a product's ultimate cost. Second, the tax code permits the partners to be taxed at the long term capital gains rates on the sale of all rights to a patent or patentable property by the inventor or a person who buys an interest in the invention from the inventor before it is commercially exploitable, regardless of the actual holding period. The third element is the decision made by the U.S. Supreme Court in a precedent setting case known as "Snow vs. Commissioner", 416 U.S. 500 (1974) which held that limited partners could offset their income with partnership research or experimental expenditures. This decision also further extended the boundaries of Section 174 to include businesses that have not yet offered any product for sale.

For example, a typical partnership would be initiated by an inventor, who as general partner would contribute his invention or idea while the limited partners provide capital to finance the required research and development to bring the concept to fruition. The partnership subsequently spends the funds for research allocating the resulting tax loss to the limited partners. This loss offsets the limited partners "nonpartnership" taxable income therefore reducing their after tax exposure and thus reducing the perceived risk of the research project. When the concept is perfected and brought to the marketplace, the general and limited partners share the income generated from the sales of the product.

Over the last ten years, many variations to this basic structure have been suggested and tested within the business community. In most cases, the partnership contracts out the

R & D to a research corporation, usually headed by the inventor. This procedure takes advantage of existing facilities, minimizing the requirement for the partnership to invest in new facilities while protecting the "trade secrets" of the inventor. Similarly, rather than manufacturing and selling the results of the research effort, the partnership will sell all rights to the invention to the research corporation/inventor in exchange for royalties based on sales. These royalties usually represent a significant proportion of revenues until the limited investors are paid back for their initial investment. At that point, the royalties decrease to a substantially smaller percentage which, by contract agreement, usually terminate after a specified period of time. In this manner, the inventor maintains control of his company and his technology based products while minimizing external debt. The limited partner/investor minimizes his risk through the tax benefits while obtaining the prospect of above average returns on his dollar if the product is successfully developed. This prospect is particularly enhanced by the stipulation that tax on the royalties will be paid at capital gains rates rather than ordinary income rates.

Although the concept described for creating an R & D partnership is seemingly simple and straightforward, there are legal and accounting pitfalls which can jeopardize the integrity of such a project. Lawyers and accountants tend to get rich in the process, but their advice, gathered from other's experience, will be required in structuring an agreement which meets the requirements of all participating groups including the IRS.

NASA may not immediately appreciate the significance of the R & D partnership in financing the commercial elements of a space station. However, it should be realized that most R & D partnerships stress the development more than the research. In other words, where capital is required to test the feasibility of manufacturing a product or creating a process for manufacturing in space, the R & D partnership may represent an appropriate mechanism for achieving that objective. Again, it should be realized that such financing usually would not stand alone. Somewhere in the process of funding a new business, venture capital will be involved as well as those elements of financing required to fabricate the manufacturing facilities, which for NASA's purposes, would be modules of a space station.

Therefore, in covering the attributes of venture capital and the R & D partnership, the basis for using these financing tools for funding the most promising commercial space activities has been established. The methods for financing the components of the space station will be addressed in an overview of project financing.

Project Financing

Project financing is another relatively simple concept that is utilized by the business community to finance large, capital-intensive projects while minimizing the impact to the sponsor's balance sheet. The basis of project financing lies in the ability to confine the financing to a particular business unit or "project" without recourse to the sponsor. Thus, the project should stand by itself as a viable business concept or have access to specified third party guarantees which will ensure the project's ability to repay its lenders.

Project financing has been successfully utilized by companies involved in the transportation and processsing of new energy resources in particular. The amount of money and the time required to build such facilities frequently places an intolerable burden on a single sponsor unless the risks and rewards can be spread among several other interested parties. Such groups could include insurance companies, upstream suppliers, and downstream customers, as well as the lending institutions themselves. Collectively, the interests of all parties are achieved, usually through intense negotiations and compromise, and the credit viability of the project is established based on the combined qualifications and commitments of its constituents.

Although simple in concept, project financings can become quite complex when the often conflicting goals and requirements of its constituents are considered. Again, the experience of other companies, both their successes and failures, can be beneficial in determining whether project financing would be appropriate for a particular application and in determining how best to minimize delays in completing the transaction.

Criteria for Implementation

As stated previously, project financings generally are associated with capital intensive business concepts that have a lifetime of significant duration. Therefore, it is necessary to consider various criteria for project financing in the context of the project phase in which these criteria are applicable.

For practical purposes, almost all projects can be divided into four distinct phases: planning, engineering and construction, start-up, and operation. The sponsor of the project will initially produce a business plan which will outline in detail the anticipated costs to be incurred, revenues, and milestones for the proposed project. In the case of a space station, the dollar amounts and time periods may vary, but the sequence of events will be the same. Thus during the planning period before implementation of project

financing for a component of a space station, the following criteria will be carefully scrutinized by lenders who wish to minimize their exposure:

- Is the primary sponsor adequately backed by equity funding? (Banks and other lending institutions are not financially backed or organizationally prepared to take equity risks.)
- Are the projections for costs and revenues conservative and based on valid assumptions?
- Is there technology risk? In other words, are there components of the project which are technically unproven and potentially unreliable?
- Are components and raw materials readily available and reliably priced?
- Is transportation for raw material and finished product available and competitively priced and will it remain so for the lifetime of the project?
- Does a market exist for the finished product? If so, is it a mature or immature market that is growing, static, or relatively unpenetrated?
- Is there a threat of technological obsolescence?
- Is the contractor or any intermediary agency considered reliable, cost conscious, and noted for delivering according to contract schedule?
- Are the management personnel experienced? Have they operated similar projects under comparable conditions and what was their track record?
- Is there sufficient insurance to cover losses beyond the control of the operators?
- Is the project going to operate in a stable political environment? In other words, will all types of regulation be anticpated, will all forms of taxation be discounted, and will changes associated with fluctuations in government be minimal?

Leasing

Although debt of some type is present in almost all forms of project financing, various forms of leasing represent an important mechanism for facilitating the flexibility required in capital-intensive project funding. The basic or true lease provides the lessor the opportunity to claim the tax benefits associated with equipment acquisition which he flows through to the lessee in reduced lease payments. The lessee, who might otherwise be unable to take advantage of the tax benefits, thus is able to reduce his cost of financing his business. In a pure sense, the lease is a form of project financing. In a broader sense, the lease is a component of larger, long term equipment acquisition which has become known as project financing in the evolving use of that term.

Leasing typically appears in a project financing in the form of a "leveraged" lease. In this variation, the lessor borrows from 50% to 80% of the funds required to purchase the desired equipment from a long term lender such as a bank or institutional investor. At this point, the simple lease becomes somewhat more complex now that a third party is involved. The debt is secured by a first lien on the equipment purchased and an interest rate is negotiated based on the credit-worthiness of the borrower and the perceived risk of the transaction. The lessor is permitted to claim all the tax benefits of the equipment purchase which will initially reduce any negative cash flow from the transaction even though interest must be paid to the lender. In the short term, the lessee also benefits due to reduced lease rates. Assuming that the use of the equipment progresses as planned, the reduced negative cash flow in the short term will accelerate growth and development of the business to a point where a positive cash flow is achieved at a faster rate. Leveraging also increases the risk asociated with unanticipated losses -- that is, leverage can work in both directions.

In leveraged lease transactions of any significance, there may be a large number of lenders and owners. Thus, frequently, an owner trustee is established to hold title to the equipment and to represent the owners while an indenture trustee is named to oversee the interests of the lenders by holding the mortgages and monitoring the periodic flow of funds. The complexity of such transactions and the resulting legal costs usually limit their use to projects involving major equipment . Hardware for a space station operation would most certainly fall into this category.

Factors that could enhance or expedite the formation of project financing transactions would include government guaranteed debt (i.e., revenue bonds, guaranteed bank debt, etc.) and/or investment tax credit and accelerated depreciation for technology investment. In particular, this is an

area where NASA and the Congress can play the most effective role by providing incentives for the investment community to become involved with space commercialization. New technology areas are always slow to attract investment dollars until one or another factor triggers the interest and awareness of investors. Positive publicity is a very important contribution. In that sense, space commercialization is receiving favorable coverage by the press. However, the public perceives that space activities are expensive and risky and prone to undefined time delays. Economic incentives would go a long way towards changing that image and putting space commericialization into a positive investment environment.

V. SPACE COMMERCIALIZATION: REMOTE SENSING AS A CASE STUDY

Satellite remote sensing, as typified by the Landsat series of satellites, has been utilized and scrutinized for more than a decade. And yet, within the government, very little has been done to understand the commercial potential of satellite remote sensing or to determine how it could be commercialized productively and efficiently. Landsat has been primarily an R & D program with heavy emphasis on the "R" and with only minor attention paid to the commercial "D". Unfortunately, this has left a very promising commercial technology with a very poor foundation for transition to private sector operations. Even the major aerospace contractors, who have been involved with the Landsat program, have a poor understanding of the business opportunities in this field. From their point of view, satellite remote sensing was only important to them in terms of government contracts and not in terms of developing a new market for earth resources information services.

The government, through the NASA Landsat and the NOAA meteorological satellite (Metsat) programs, has contributed significantly to the future economic potential of satellite remote sensing. In spite of this contribution, however, an unfortunate lack of understanding has developed concerning the context in which remote sensing fits into a commercial environment. In NASA's sphere of operation, remote sensing is primarily an aerospace technology. But in the commercial world, remote sensing is a computer and information technology and it should be packaged and marketed accordingly.

Of greater significance, however, is the fact that remote sensing has not been positioned by the government as a potential commercial technology; therefore, it has remained unnoticed by the financial community. Specifically, no government agency has ever conducted market research to define the true potential of an information system based on real-time data acquisition from a network of geosynchronous and low earth orbiting satellites. To a great extent, knowledgeable private sector groups understand that the potential gross revenues derived from all components of an earth (land and ocean) resources and environmental data industry can be numbered not in the millions, but in the billions of dollars annually.

This past underestimation of the commercial potential of satellite remote sensing certainly does not help NASA now when promoting remote sensing as a component of a commercial space station program. Estimates by TRW in their Space Station Needs, Attributes and Architectural Options Study (SSNAAO) indicate that the contribution of the space segment (namely, the sensors and platforms) of remote sensing to overall space station revenues could be as much as $5.15 billion between 1995 and 2000. However, this contribution

to the support of the space station program is highly dependent on aggressive development of the satellite data user market at this time, paralled by a dedicated commitment to developing a commercially viable follow-on to the Landsat program.

The government's past attitude towards remote sensing may be attributed to its orientation toward research rather than business in space. There is also a seemingly "governmental" quality to the meteorological satellite observation process. Nevertheless, it is apparent that the current activities of the Landsat program will be transferred to the private sector within the next several years with other application functions (i.e., ocean and meteorological remote sensing) being assumed by private companies during the latter part of this decade as a function of a gradual transition to commercial operations.

Terra-Mar recognizes that future revenue from appropriate satellite sensors is directly tied to growth associated with the next generation of computer services. In this context, digital satellite imagery will be a valuable source of input into earth resources information services. Within the private sector, the infrastructure for this service capability is now in the development stage. Highly refined applications software for converting imagery into information will soon greatly expand the current limited user base. Furthermore, computer networks and distributed processing will provide convenient access to new markets for specialized earth resources data bases. This is a factual not a speculative scenario that is based on generally accepted trends which are fundamental to all computer service companies.

In building investor confidence in the commercial potential of remote sensing, it is essential to establish the connection between these trends and the commercial opportunities that accurate information generated from satellite imagery will provide. Assessing and analyzing the market becomes an important function of capitalizing a new industry.

Assessing the Potential Market

Previous government studies have at best defined the value of satellite remote sensing in terms of a "cost-benefit" analysis using techniques inappropriate for assessing future high-technology markets. Specifically, the mechanism for gathering information about the future user community -- the market survey -- has misrepresented the substantial potential of an earth and environmental resources information industry. The market survey can be a very useful tool in predicting sales figures, depending upon how the information is gathered and how it is utilized. In the

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case of past surveys of users of remote sensing data, the general questions have been along the lines of "...how would you use remote sensing data", "... how much remote sensing data would you buy", and "...how much are you willing to pay for remote sensing data". The absurdity of such questions can be put into some perspective if one considers how a "potential customer" for computers or plain paper copiers would have answered similar questions in 1950. Most people cannot even begin to imagine how remote sensing data could relate to the way they do business or to how they make decisions.

In order to correctly assess the potential market for remote sensing "information" -- that is, highly processed and refined remote sensing data -- one must ask questions which relate to how people use any type of earth resource information in their business and how critical this information is to their decision making process. This type of information could be as seemingly mundane as a newsletter from the state fish and game department or the morning weather, livestock, and commodities report on the local television news. It could also be as expensive and complex as a $100,000 per year crop forecasting service received daily by a commodities brokerage business. Each use of information is extremely significant for the forecasting of the market for remote sensing derived products. Even this market research is irrelevant if put into a market forecasting model which does not account for the real world environment. In the case of forecasting remote sensing information markets, models which do not include industry concentration (revenues per establishment), user sophistication (ability to utilize and adapt to computer generated products), and technology leverage (growth of computer generated services) should be considered useful to the academic economist but otherwise useless in a commercial environment.

Unfortunately, such an incorrect market analysis has been generated in past market forecasts from current sales of Landsat data from the EROS Sioux Falls Data Center. Sales of products from an R & D system in a format not readily interpreted by the "masses" does not constitute the basis for accurate market projections.

In evaluating market potential, Terra-Mar has assessed the gross requirements of users for all forms of renewable and nonrenewable resource and environmental information in terms of operating revenues which are specifically affected by the availability of that information. Thus, an oil company managing a $100 million offshore oil field may spend $500,000 per year for wave, current, and meteorological information derived from satellite data and associated value-added services. Or, 10,000 commodity brokers may each utilize $50 worth of a commodities information service in making trades equaling $50,000,000.

Based upon the availability of appropriate remote sensing data, earth resources and environmental information services will eventually penetrate and expand these current markets with improved products. Projecting the growth and development of such a business becomes a function of quantifying the size of that potential market and then calculating rates of market penetration based on historically documented algorithms for comparable technologies (namely, those based on computer and communications technology).

Terra-Mar's market projections derived from analyzing these marketing and technological trends provide a positive basis for pursuing commercial satellite remote sensing services. These projections assume an aggressive marketing environment -- one that is unregulated and very competitive. Similar promising revenue estimates for materials processing products and services have been made outside the government. NASA must recognize that the technologies, which are partially the fruit of NASA's own R & D efforts, must be nurtured in an environment stimulated by the application of creative marketing techniques. The creation of the technology establishes the potential of a new business. Application of sound marketing and management techniques makes that potential business a reality.

The Leverage of Improving Technology

To a great extent, growth in the markets for earth resources and environmental information will be made possible by advances in semiconductor and computer technology. The growth in the sales of personal computers from zero in 1976 to over $6 billion in 1983 is indicative of a trend towards less expensive, distributed computing which will shape the marketing strategies for computer services in the future. In essence, the personal computer has created a mass market for software and data services on an individual level. Like the scientific hand-held calculater of the last decade, a high percentage of scientists, engineers, and businessmen will own a desktop personal computer to use in their day-to-day decision making process. It will not be a luxury but a necessity.

In this marketing context, remote sensing data will become an important component of the future information revolution. Terra-Mar has determined that a substantial proportion of important decisions made by the business community are related to having accurate information about the earth's resources or its environment. Improving the raw satellite imagery with value-added services -- essentially, customizing the data to user needs -- will make remote sensing data a strategic element of the future decision making process of international business.

In addition to advances in computer technology, the next decade will see improvements in the methods of deploying orbiting earth sensors. More reliable, interchangeable, and thus less expensive sensor components will be operated from space platforms such as the Fairchild Leasecraft and the MBB SPAS in coordination with manned space stations. On these platforms, scheduled maintenance and repair will prevent the costly loss of satellite sensor systems, as previously experienced with Seasat, for example. The requirement of efficiency and economy will replace the "gold-plated" specifications generated by the previous era of R & D sensors.

Approaching the Investment Community

Unfortunately, the investment community has not been well informed about the commercial opportunities regarding utilization of remote sensing technology. Government officials have not only failed to educate Wall Street but have also failed to understand how private investors can play an important role in developing this strategic technology. As mentioned previously, investors are guided by certain criteria in evaluating prospects for placing their funds.

Four criteria are particularly applicable in the case of remote sensing. First, is the technology far enough removed from research and development that there is small risk of technical surprise along the path to the marketplace? Second, is this a market with substantial opportunity for long term growth? Third, after considering development and operating costs, are revenue projections sufficient to provide adequate return-on-investment (ROI) in comparison with other investment opportunities? And fourth, is there minimal near and long term risk of the type of government regulation that could inhibit earnings growth? In other words, are we dealing with a politically benign technology?

Ten years of successful R & D in Landsat and related environmental satellite programs will provide the basis for initiating commercial remote sensing ventures with little threat of technical uncertainties or unknowns. Solid state sensor technology will minimize many of the risks of mechanical sensors, while improved modes of deployment such as SPAS and Leasecraft serviced through a manned space station can minimize the risks of on-orbit failure.

Discounting the government evaluation of remote sensing generated information markets, private studies such as those prepared by Terra-Mar adequately document the potential of a market for products and services primarily generated from the availability of appropriate remote sensing data. Paralleling other computer generated information service markets, this business should generate approximately $12 billion in revenues (in constant 1980 dollars) from sales of

data, computer hardware and software, and value-added services by the year 2000. Such rapidly growing and sustained market opportunities are currently highly valued by the investment community.

Thus, the projections for revenues and profits become equally appealing as costs decrease with improved computer and sensor technology, while progress along the "learning curve" creates well defined methods for decreasing unit cost for data generation. Subsequently, remote sensing will follow the trend of other computer technologies as near term dominance of hardware sales is rapidly displaced by requirements for software and then raw data, as the market becomes more broad-based and sophisticated in its utilization of available products.

This leaves the fourth factor -- the issue of politics -- as the remaining unknown and the single issue which could inhibit commercial development of remote sensing products and services. The current controversy over the disposition of Landsat 4 and the environmental satellites poses a serious problem for the business community to overcome. Specifically, Landsat 4 and the Metsats are encumbered with technical and political problems which make their transfer to the private sector rather complex. The original value of the satellite and related data processing assets is significant; however, on the open market, that level of technology is considered obsolete. Given the computer technology which is available today and which will make another substantial leap by 1984, Landsat 4/Metsat-type equipment, primarily oriented for R & D applications, could be considered in financial circles to be a commercial liability. There is also a negative stigma associated with "Landsat" as a commercial concept. The entire process of "analysis" has politicized Landsat to the extent that the financial community views Landsat with a certain skepticism -- it is expensive, unreliable, and may entail unknown political traps.

Nevertheless, Landsat 4 and the Metsats do represent a significant contribution to our understanding of the technology associated with developing viable commercial information products. The addition of the Thematic Mapper to Landsat 4 has provided new insights into the potential usefulness of satellite resource surveillance. However, Landsat 4 is not configured to be an operational satellite system, and no investor who is seeking to compete in an open marketplace would consider owning that system. The NOAA and GOES environmental satellites, although existing in an operational environment, are similarly not configured for commercial utilization. The government's preoccupation with "selling" Landsat and NOAA satellites has missed the true objective of promoting satellite remote sensing as a viable commercial technology. Emphasis should be placed on creating incentives for investment in the next generation of reliable and efficient satellite sensing systems, rather

than on unloading the product of past R & D programs. Similar errors cannot be made in developing commercial space station programs, otherwise investors will show little interest in these programs.

The proper government orientation and strategy should be to stimulate the groundswell of value-added activity which is already occurring, thereby increasing revenues from satellite data sales as new applications become entrenched in the marketplace. Strength among private sector operators will eventually permit backward integration into data receipt and archiving as well as the development and operation of orbiting sensors. In this mode, healthy competition will encourage the creation of new applications software as well as encourage the companies with the best capabilities to assume a leadership role in developing a fully integrated earth resources information system.

In this frame of reference, the investment community can properly interact with those private companies, objectively evaluating the strengths and weaknesses of various competing concepts, evaluating their management's strategic planning skills and knowledge of the market, and putting each to the ultimate test -- looking at the "bottom line". The government should not compete with Wall Street in making these decisions. The government's self-interest, as probably the largest single customer for earth resources information services, will be best served by letting the marketplace determine which companies are best qualified to own and operate remote sensing satellite systems. A similar approach would expedite and enhance the investment potential of other commerial space activities.

Creating an Investment Model for Commercial Remote Sensing

Assuming a creative and stimulative transition of satellite remote sensing from current government operation, a remote sensing/earth resources information industry can finance its space segment using many of the techniques and tools outlined in Section IV. A further assumption must be made that the cost of remote sensing systems will decrease substantially during the next decade as improved electronics are incorporated into operational sensing platforms. As discussed previously, this capability will be further improved by the ability of sensing platforms to be serviced on orbit by astronauts from a manned space station. Changes in the competition and cost structure within the aerospace industry will also lead to the availability of space qualified components at prices approaching those for aircraft avionics. Within this structure, multiple sensor "platform" systems will be feasible under project financing guidelines.

VI. SPACE STATION MODULAR FINANCING

Various circumstances may evolve which will dictate the design and operating priorities for space station development. Assuming that commercial applications become a significant factor in the planning process, a strategy must be implemented that will accomodate differing requirements for orbiting facilities by various commercial users. Besides being sound from an engineering point of view, this strategy must also be financially viable. Ideally, early commercial users of an orbiting space station will pave the way for other users. For example, every new technology market has its identifiable source of market leverage. In this situation, communications provides that source of leverage. Or, in the parlance of corporate America, telecommunications could be the "cash cow" of space commercialization and could provide the core facilities to support commercial remote sensing and materials processing projects.

Commonality and interchangeability of hardware will become a key criterion not only for operational convenience but also to minimize fabrication costs and consequently investment risk. Investors will be favorably inclined towards facilities where the risks associated with engineering and fabrication are borne by a number of users. "Custom" facilities have the aura of high cost and unknown operating history. Those risks are commonly taken for granted by NASA but are to be avoided if possible when presenting projects for financing to the investment community. If engineering risks are to be part of any project, they should be "packaged" as part of an appropriate financial vehicle -- namely, venture capital or R & D limited partnerships.

In that sense, for financing reasons the space station should be engineered in a modular framework that is both functional and practical. Individual projects planned for the separate space station modules (or components), and their operating facilities, can then be matched with the financing mechanism best suited for the element of risk and the return on investment associated with that project. In reviewing the space station feasibility studies prepared over the last decade, Terra-Mar has concluded that an appropriate concept reflecting this logical, modular approach is embodied in the "Manned Orbital Systems Concepts Study" (MOSCS) prepared by McDonnell Douglas for NASA in 1975. Vestiges of this philosophy can be found within the reports completed earlier this year in response to the SSNAAO, although there appears to be an inclination to engineer a facility on a more elaborate scale. The reader is referred to the MOSCS Executive Summary for a review of a conceptual approach to a commercial space station which, if repackaged for Wall Street today, would probably be favorably received.

VII. SPACE STATION INVESTMENT SCENARIO

There are many possible variations on how and under what conditions the investment community would participate in some component of commercial space station financing. For illustrative purposes, this section contains an investment scenario in which the previously discussed financing techniques are interwoven into a deal reflecting the priorities of investors as they relate to an actual opportunity. In this analysis, all individuals and companies are fictitious and the circumstances do not represent current or proposed ventures of any kind.

Cast of Characters

Tom Evans	- Senior Chemical Engineer at Consolidated Elctronics Industries
Fred Dexter	- Tom Evans' boss
Roger Barrett	- Fred Dexter's boss and V.P. of Engineering at Consolidated Electronics Industries
Pete Baxter	- Tom's brother-in-law and an investment tax lawyer with Kroger, Michaels & Cresap
Phillip Donley	- President of Aerospace Devices, parent company of Space Facilities Inc.
Bob Lambert	- Board member of Aerospace Devices and retired bank executive
Gary Hansen	- Board member of Aerospace Devices and former president of Crosby Steel
Ted Lambert	- Bob's brother and a partner at Kroger, Michaels & Cresap
Al Pearson	- Pete Baxter's tennis doubles partner and a partner in Advanced Technology Concepts

Tom Evans is a senior chemical engineer at Consolidated Electronics Industries in Lake Pleasant, New York. He has worked for Consolidated for twenty-five years and now heads their semiconductor crystal fabrication laboratory which synthesizes and tests various materials used in semiconductor fabrication. An aerospace buff for many years, Tom has been intrigued by the possibility of growing pure crystals of gallium arsenide in microgravity. He knows that NASA is building a space station where migrogravity experimentation time will be available at a reasonable cost for R & D and

feasibility studies. Thus inspired, he took some of his own time over a three-month period to develop the chemical analysis, engineering fabrication plans, and the business plan for a gallium arsenide crystal growing project which he subsequently presented to his boss, Fred Dexter, for review. Fred was impressed, put his stamp of approval on the project, and referred it up the chain of command to the V.P. of Engineering, Roger Barrett.

Consolidated Electronics, for reference purposes, is a $10 billion conglomerate with investments in everything from aerospace to agribusiness. Forty percent of its annual revenues is derived from government contracts, primarily with the Department of Defense. However, 1986 was not a good year for Consolidated. Hit hard by the unexpected recession, Consolidated got caught with "fat" inventories when contracts were cancelled and anticipated orders did not arrive. In fact, its defense business was the only factor which kept Consolidated in the black for the fiscal year.

Roger Barrett considers these facts as he reviews Tom Evan's proposed project. Roger is also only three years from retirement and is being considered for promotion to Senior Vice President during the next annual review. He decides that he does not want to give the impression to the boys at the top that he is experiencing early senility by advocating any "Buck Roger" ideas in this economic climate. Therefore, he places his REJECT stamp on Tom's proposal and passes it back down to Fred Dexter.

Tom Evans is very disappointed. He thinks out loud, "what a great opportunity for Consolidated to utilize their experience in semiconductor R & D and to get a leg up on their competition. But those guys at the top must know what they're doing -- they really have the big picture."

By chance, Tom tells his story to his brother-in-law, Pete Baxter, who is an investment tax lawyer with the New York investment banking firm of Kroger, Michaels, & Cresap. Pete is intrigued by Tom's project. Pete knows that Tom is the best in his field, and he has a feeling that a recent project in which he was primary legal counsel may be related in some way to Tom's idea.

K.M. & C. acted as an advisor and broker in a project sponsored by Space Facilities Inc., a subsidiary of Aerospace Devices, a $100 million fabricator of specialty electronics components for NASA and the Department of Defense. Aerospace Devices' president, Phillip Donley, wanted to exploit his company's distinctive competence in building custom aerospace hardware in the new arena of commercial space operations. Phil had been impressed two years before at a NASA briefing where the NASA brass really put forth a well-oiled plan for stimulating commercial space activities. Phil organized a plan with his chief of engineering to build

materials processing modules that would be compatible with the space station design established by NASA.

In essence, it was NASA's innovative approach to this design that convinced Phil they were really serious about commercialization. First, they locked in a design within a year of the SSNAAO studies thus giving everyone outside the system a chance to evaluate the design and come up with their own interfacing ideas. Second, the design was a masterpiece of simplicity -- flexible, taking advantage of all that was learned in the Skylab and Shuttle programs, and incorporating the latest advances in computer and electronics technology. For Phil, it was a piece-of-cake to come up with a compatible design that was equally flexible, using off-the-shelf technology and their own ingenuity to fabricate a relatively inexpensive module for materials processing experimentation.

Phil presented the idea to his board of directors. Bob Lambert, a member of the board and retired bank executive, was enthusiastic but had some reservations about getting such a project financed. He told Phil after the board presentation that Aerospace Devices really needed a customer for the module or at least a couple companies who were willing to sign up for long term contracts to rent space on one or more of the experimentation modules. Gary Hansen, another board member and former president of Crosby Steel Corp., had heard that his former company had been doing some microgravity metal alloy experimentation with NASA Marshall and offered to see if they were interested in committing to some long term project. Well, Crosby Steel was quite cooperative, particularly after realizing that all their R & D experimentation could be expensed, rather than capitalized, based on the 1984 Space Commercialization legislation that Congress had passed.

Thus, Aerospace Devices received a contingency "take or pay" contract from Crosby Steel for module rental as well as a similar contract from the National Science Foundation for collective university studies. At that point, Aerospace Devices also established their Space Facilities subsidiary which sought additional potential large and small customers through advertisements in various professional journals. NASA, impressed with Aerospace Devices' concept and their initiative, expedited the engineering review documents and enthusiastically gave the materials experimentation modules their seal of approval.

Then, Bob Lambert stepped back into the picture and got the wheels turning at K.M.& C. where his brother Ted was a partner. Ted and Bob put their heads together and decided that a project financing approach would be the most appropriate form of financing for the materials processing modules. Pete Baxter, Tom Evans brother-in-law, was in charge of writing the legal opinion for the project financing, in

collaboration with Aerospace Devices' counsel, and orchestrating the final negotiations for a leverage lease with General Credit Corp. backed by loans from Gotham National Bank, the lead lender among eight participating banks. Aerospace Devices could not take advantage of all the tax write-offs associated with the fabrication of experimentation modules, particularly the 15% investment tax credit and accelerated depreciation which was also part of the Space Commercialization legislation. Thus, the project financing involved the sale of the modules from General Credit who in turn leased them to Space Facilities Inc. for resale of services to their customers. Outer Limits Insurance, Inc. brokered the insurance covering all risks incurred in transporting and operating the microgravity modules on orbit. So, all issues of risk, liability, and compensation were covered by a complex but mutually acceptable project financing agreement.

In reviewing the project financing documents, Pete Baxter saw an opportunity for his brother-in-law, Tom Evans. Space Facilities was offering special incentives for small experimental users to rent space for 250 hours or more of their microgravity module time. Tom did not have the money or even his company's backing but he did have the reputation and a great concept on paper. Pete called his tennis doubles partner, Al Pearson, who was a partner in the venture capital firm of Advanced Technology Concepts, Inc. (ATC), and arranged a meeting between him and Tom. The meeting went very well and Fred and his partners decided to back Tom's gallium arsenide crystal business, to be known as MicroSpace Devices, with a $1.5 million equity investment -- however, the proof of concept would require up to $6 million in equipment, processing facility time on the Space Facilities' microgravity module, and transportation costs on the shuttle. And there was the issue of release of proprietary ideas from Consolidated Electronics.

Good lawyers and good brokers can solve most problems, at a price. The REJECT stamp on Tom's proposal was his ticket to freedom from Consolidated since employers must either utilize their employees ideas or provide them the opportunity to develop their ideas on their own, according to legal precedent. The $6 million issue was settled with an R & D limited partnership brokered by ATC's parent, Ferrill Bench, and offered through their 276 offices nationwide. With "Space" and "Semiconductor" in the same prospectus title, it was an instant sellout, in spite of all the boilerplate warnings and disclaimers.

Now, hypothetically, we are in the year 2000 and we are reviewing the long term fruits of this initiative. MicroSpace Devices, better known as MSD to the financial community, is a $3 billion annual sales company, dominating the market for ultra fast logic devices, primarily designed for the MEGAVAX type computer that most people wear on their

wrist. Aerospace Devices, referred to as ADI, now has annual sales of a $2.5 billion supplying microgravity manufacturing, processing, and habitation modules to their estimated 2500 customers worldwide. They have also just entered the market for prefabricated hotel modules which they will initially sell to Hilton International. By the way, NASA rents hangar and habitation modules from Space Facilities for their interplanetary exploration vehicles. Collectively, the Gross National Product has been expanded by $100 billion by direct and indirect capitalization expansion due to space industrialization. And the federal government no longer has a national debt, in great part due to the additional tax dollars generated by commercial space development.

For review purposes, the foundations of this free enterprise fantasy may be traced in Figures VII-1 and VII-2 which diagram the ADI project financing and the MSD limited partnership and venture capital funding.

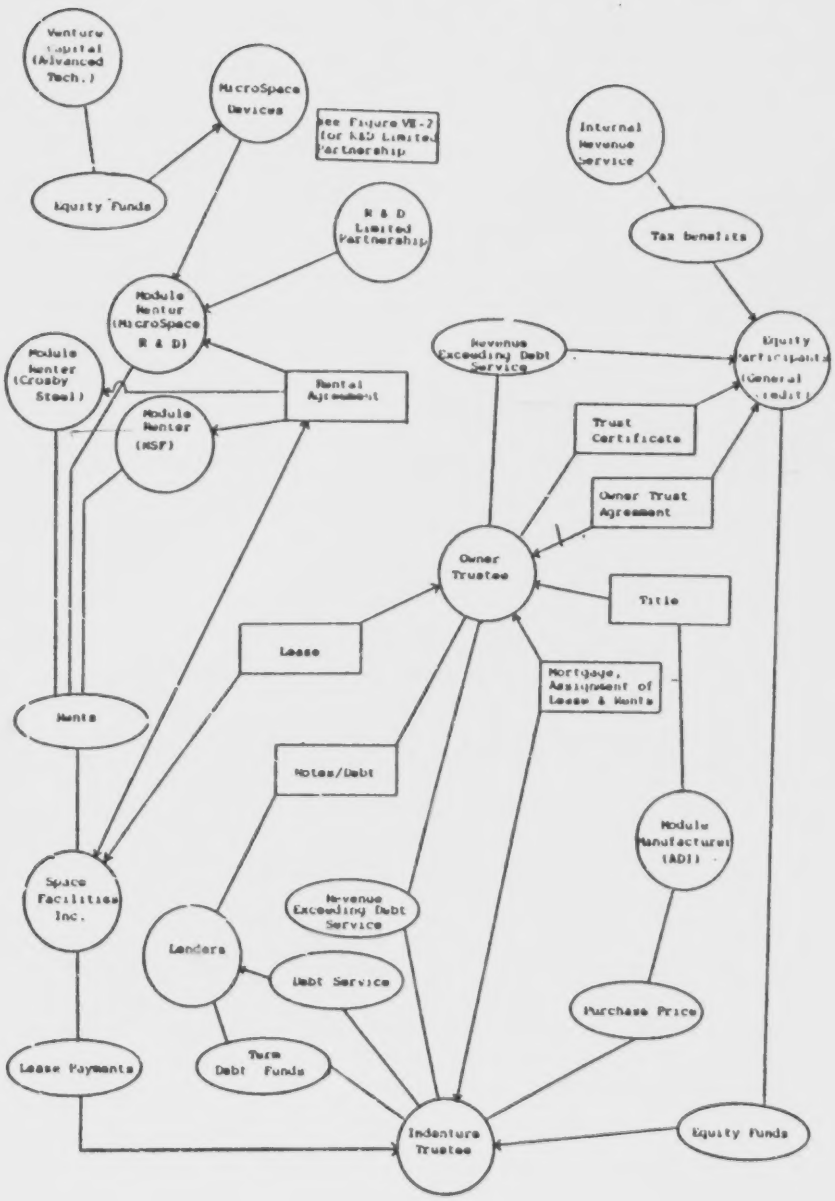
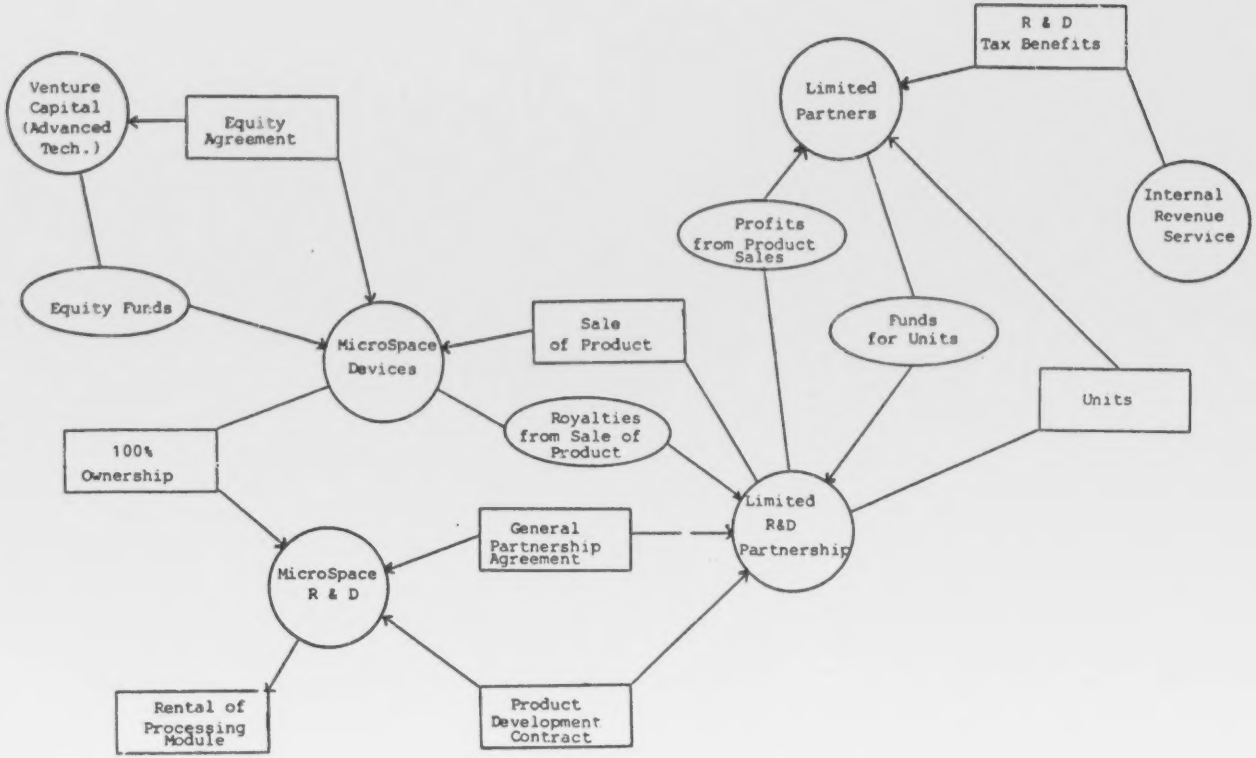


Figure VII-1: ADI Space Station Module Project Financing.



The MicroSpace R & D Partnership

Figure VII-2

VIII. LEASE VS. BUY: NASA HAS A CHOICE

In the previous sections, it was assumed that NASA would be the prime instigator in establishing a space station for commercial or any other purpose. Supposedly, this would mean that the government would own the space station and, through NASA, would lease facilities and thus provide services for a fee. Conceivably, one could ask whether, on earth, the government should be in the business of building industrial parks and leasing these facilities to the private sector. In reality, although the government does own a large number of the office buildings and laboratories which it utilizes, it also leases a considerable number of buildings from private owners and real estate developers.

It could be argued that a space station is nothing more than an industrial park in space -- in essence, orbiting real estate. Should NASA be doing a lease vs. buy analysis in determining its best utilization of government funds? Perhaps yes. Is there something so overwhelmingly governmental about space that the private sector should not be given the opportunity to take the initiative? Perhaps no. Definitely, the military's requirements for secure facilities may preclude their operation by civilians. If this factor is an overriding consideration in our future space programs, then the government should take the lead in developing appropriate facilities for its own use.

However, if military applications do not represent the primary reason for being in space, the lease vs. buy decision should certainly be considered, particularly if the concept of space commercialization is to be taken seriously. Why? For the reasons brought up initially in Section II. Can NASA guarantee its customers continuity of prices and policy through changes of administration and fluctuations in the attitude of a Congress that continually revises budget priorities? It is extremely unlikely. On the other hand, NASA could lease all or part of a space station from a private financial institution and expect that contract to remain in tact through the lifetime of the facility. That is the reality of law and the art of writing a good contract.

What about the cost? Here, there are trade offs that must be considered. In favor of leasing: deferred vs. upfront payment, tax revenues generated by leasing profits, and interest dollars saved if deficit financing is involved. In favor of buying: elimination of tax deductions associated with depreciation and potential revenues gained from leasing facilities to nongovernment customers. A sensitivity analysis could be run to analyze the effect of various tax considerations and interest rates on this type of trade-off analysis. However, a more appropriate and perhaps less easily answered question would be -- what levels of efficiency and economy could be achieved by an appropriate pri-

vate space station operator as compared to a government agency? Would private lenders backing a private space station operator impose greater discipline on the contracting and facilities management process thus promoting more efficient operations? Would the construction and operation of a private space station be comparable to the manufacture and operation of airliners -- delivered on schedule for the contracted amount, operated and maintained according to strict guidelines motivated by legal, liability, and profit considerations? Would the economies achieved through business and legal discipline reduce NASA's flexibility in accomplishing its stated mission, specifically, leading edge research and development in aerospace applications?

Of course, there is the middle road. The government through NASA could finance the core facilities -- the solar panels, docking ports, cooling and radiation devices, and telemetry facilities -- while the private sector would own and finance its own manufacturing and processing modules.

To a great extent, the answers to the above questions go beyond economics and enter the arena of establishing and perhaps rewriting government policy. However, it should be realized, that the investment community will more readily interface with a system that it understands and respects, namely, a system of binding contracts and economic incentives. NASA's commitment to space commercialization may be judged on the basis of NASA's willingness to play by those rules. The commitment of private dollars to a commercial space station project will be impacted accordingly.

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E. Living in Space

MAN IN SPACE

SPECIAL REPORT:

SPECIAL REPORT: MAN IN SPACE

Space has become as familiar a dateline as Beirut or Moscow, as NASA pushes forward with its most ambitious plans for man in space since the Apollo moon landings. February's historic untethered spacewalk has set the stage for a bold attempt in April to repair the disabled satellite Solar Max. It has also given impetus to President Reagan's call for a space station, where people will live, work, and dispatch manned and unmanned missions to the far reaches of the solar system. In this special report, DISCOVER examines America's manned space program, beginning in Part I with a report on a trouble-filled shuttle mission that was highlighted by one symbolic and glorious moment. Part II previews the Solar Max rescue, while Part III describes the proposed station in space. Finally, in Part IV, some thoughts on the manner of it all.

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PART I: THE MISSION

IN THE ARMCHAIR OF THE GODS

The first solo voyages by untethered astronauts and a misty Florida landing redeem a frustrating shuttle flight

In a giant leap for American spacefarers, Bruce McCandless (above) and Robert Stewart (below) flew untethered from the shuttle in NASA's new jetpacks

BY DENNIS OVERBYE

Sunlight, creeping around the blue limb of the earth 175 miles below, began to wash over the hull of the space shuttle *Challenger* as Bruce McCandless, in the shadows of the cargo bay, asked permission to abandon ship. "I'm going to head on out of the bay," he crackled, "with your permission." With his left hand he pulled up on a small handle on the armrest of his square white backpack, which looked for all the world like a bulky, legless chair. A burst of compressed nitrogen gas shot from tiny thrusters, and McCandless rose head first out of the shuttle, his dangling legs silhouetted against the bright cloud tops of the earth. As he cleared the bay, the astronaut twisted another knob on his right armrest and flipped to face the shuttle. Then he backed cautiously off into the void, dwarfed by the blackness around him as he receded. "This is neat," he reported. Then, looking down, he exclaimed, "Looks like Florida—it is Florida! It's the Cape!" Sailing over the clouds at 17,000 miles per hour, McCandless had become a human spaceship.

The image of that moment will linger as long as humans fly and dream of challenging the stars. Powered by Buck Rogers backpacks, known as manned maneuvering units (MMUs), McCandless and fellow astronaut Robert Stewart became the first human beings to venture from their spacecraft without a lifeline. Their untethered flights, their ability to navigate freely, away from the shuttle, cleared the way for a host of new activities in space. Among them: the first space rescue—the scheduled capture and repair in April of the disabled Solar Max astronomical satellite (see page 20)—and the assembly of an American space station by the early 1990s. Said McCandless, "We've opened a new frontier."

For much of *Challenger's* eight-day flight in February, it hardly seemed that way. Two $75 million communications satellites were lost in space; the shuttle's robot arm developed a bad wrist; a $450,000 balloon exploded in space; the shuttle toilet clogged again; and on its long-awaited, first-ever landing at the Kennedy Space Center in Florida, the shuttle smacked into a bird.

NASA had been determined to get the first flight of 1984 off the ground on time and successfully, especially after President Reagan, only a week before lift-off, announced his support for the agency's long sought space station. And *Challenger* did roar aloft on time on February 3. Heading the five-man crew on his second shuttle flight was Vance Brand, 52. Assisting him were pilot Robert "Hoot" Gibson, 37, and mission specialists McCandless, 46, Stewart, 41, and Ron McNair, 33.

The first order of business was to launch the communications satellites: Westar VI, owned by Western Union, and Palapa B2, belonging to the Indonesian government. To do their job of relaying data and communications, such satellites have to be in geosynchronous orbit, 22,300 miles above the Equator, where their orbital motion just matches the earth's rotation and they hover over the same area of the globe. After being sprung from the payload bay, the nearly identical satellites were to be carried into high orbit by bulbous little booster rockets known as PAMs (payload assist modules). The same combination had worked well five times on previous shuttle flights. On the first

McCandless in space: "Are you going to want the windows washed while I'm out here?"

day, however, after being deployed flawlessly from the shuttle, Westar disappeared. NORAD radars found it, in good health but useless, in an elliptical orbit that took it to a maximum height of only 1,400 miles.

While engineers huddled over data from Westar and checked out the satellite in an effort to find out what had gone wrong, the Palapa launch was postponed and the crew moved to their next task, practicing approaches to another spacecraft. The plan was to launch a Mylar balloon 6.5 feet in diameter from the cargo bay, back away 100 miles or so, and then close back in on it using radar and star trackers. The balloon was in a canister that was supposed to be yanked open by stays as it left its cargo bay cradle, the way a static line opens a parachute. Instead, the stays lifted off as well. Then, reported Brand, "it blew up." Luckily, the crew was able to track a piece of the balloon and gain confidence that the radar will work on the Solar Max mission.

Finally, when technicians were unable to find anything wrong with Palapa, Indonesian officials gave the go-ahead for launching it. A television camera on the end of the shuttle robot arm relayed pictures of the PAM firing, which seemed to fade too soon. Sure enough, Palapa too was lost and then found, also in a low elliptical orbit. On both satellites, the booster rocket had apparently fired for only about 15 seconds instead of 85 as planned.

The succession of glitches cast a pall over *Challenger*, but the crew could still look forward to day five—to the debut of the manned maneuvering unit and a whole new way of flying. Each of the $15 million bulky white backpacks, built by Martin Marietta, runs on compressed nitrogen, which is squirted out of 24 little vents in response to the hand controls. Were an astronaut to keep the throttle down all the way until he ran out of gas—about four minutes—he could accelerate to a top speed of about 45 miles per hour. At that pace, he could never outrun the shuttle, which could quickly catch up to him if he got into trouble and scoop him up in the cargo bay. For that reason, NASA felt no need for McCandless or Stewart to use tethers, even on the MMU's maiden flight.

For McCandless, the morning of day five had been a long time coming. The son and grandson of navy officers, an avid environmentalist, and past president of the Houston chapter of the National Audubon Society, he graduated second in his class from the Naval Academy, and flew Navy jets before becoming an astronaut in 1966. This was his first space flight, and it was fitting that he test-fly the MMU because for almost all of his years as an astronaut he had been involved in designing and testing it. Says Johnson Space Center engineer and jetpack designer Ed Whitsett, "Nobody has left his stamp on any instrument in space like Bruce has left his mark on the backpack."

As Stewart watched, McCandless climbed into his backpack and checked out the controls while it was mounted in a wall rack in the cargo bay. Then he floated away from the wall and began flying around the bay. Meanwhile, Stewart practiced manipulating tools in zero gravity at work stations designed to resemble satellites that astronauts hope to repair in space some day.

McCandless's historic first voyage took him 150 feet away from the mother ship and lasted about twelve minutes. Scudding alone and tiny over the cloud tops far below, he looked like nothing so much as a Zeus blown by some cosmic gust from his Mount Olympus perch, throne and all.

After moving as far as 320 feet from the shuttle, he approached again and asked, "Are you going to want me to wash the windows or anything while I'm out here?" His kind offer refused, it was Stewart's turn to take the backpack. "Enjoy it," said McCandless. After repeating warmup maneuvers, Stewart headed into the void at the brisk speed of .7 miles per hour (relative to *Challenger*), prompting Brand to tell him to slow down. After pausing at 150 feet, Stewart ranged out to 305, and then came safely back.

McCandless's fun was not over. He stuck his feet into restraints clamped onto the end of the robot arm, and was given a ride around the cargo bay by McNair, operating the arm from inside. Anchoring themselves on the arm will give future astronauts leverage when they do work in space. "Just remember," McCandless warned McNair, "one false move and it's *plop*."

After a day of rest, McCandless and Stewart took another space walk, but trouble struck again. So astronauts could practice grappling with a rotating object—like Solar Max—McNair had planned to lift up a German instrument platform (used to float instruments temporarily in space) out of the cargo bay and spin it on the end of the robot arm. The platform was equipped with a grappling pin, and the astronaut carried a grapple similar to the one on the end of the

robot arm. But one of the arm's wrist controls would not work, and controllers decided not to press their luck. McCandless and Stewart, taking turns flying the second of the two backpacks on board, practiced docking to the stationary platform, and NASA pronounced itself satisfied. As they were finishing up, a loose foot restraint—a platform about the size of a bathroom scale—floated out of the bay. Deciding that there was enough junk in orbit already from exploded balloons and dud rockets, pilot Brand sidled the shuttle over to the runaway equipment, and McCandless slid along a handrail to the rear of the cargo bay and plucked it out of space. Said McCandless, " 'We deliver' may have been the motto of the fifth shuttle crew, but we also pick up."

Pressed on how it felt to fly the backpack, Stewart modestly explained that he considered himself merely a test pilot flying a new machine. Then Brand added, "But in the cabin, they call each other Flash Gordon and Buck Rogers."

There was one more milestone for Buck, Flash, and the rest of the crew, one that long had eluded NASA: landing the shuttle on a new three-mile runway at Kennedy Space Center, where shuttles are launched. Bad weather last June prevented the crew of the seventh shuttle mission from landing in Florida, but this time the skies were clear. NASA patrols made several sweeps during the night preceding the landing to hustle away any alligators or wild pigs that might have wandered onto the runway from the surrounding wildlife sanctuary (none had). *Challenger* re-entered the atmosphere near Indonesia, swooped across the Pacific, the Gulf of Mexico, Florida, and out to sea, did a U-turn, and sailed down over the palm trees through a flock of birds. As the shuttle touched down, two and a half inches off the center line of the runway, vortices of fog twirled at the ends of its wings. After an initial examination, the spacecraft was pronounced to be in perfect shape, except for four tiles (broken, NASA thinks, by ice during a water dump in orbit) and its landing brakes, which have to be replaced.

As DISCOVER went to press, NASA and industry engineers still had not pinpointed the cause of the twin satellite failures, but shuttle head General James Abrahamson vowed that "every available resource will be used" in the investigation. NASA suspects that the solid-fuel mixture used in the PAM rocket engines may have been defective, and blew apart, prematurely snuffing out the rocket flame. Pressed to find an answer before the next satellite launch from the shuttle, scheduled for June, the agency made plans to test-fire other rockets packed with fuel from the same batch.

Western Union and Indonesia stand to collect $75 million each from insurance underwriters, who warned that as a result, insurance costs for communications satellites would go—well, sky high. Although NASA claims it is not responsible for what happens once a satellite leaves the shuttle, the agency is concerned that it might lose customers. In fact, Westar was once slated to be launched by the trouble-plagued European Arianne rocket, but Western Union backed out of its date with Arianne to take advantage of an earlier slot with the shuttle.

NASA is already investigating the possibility of retrieving the satellites. Says Abrahamson, "If they ask us—seriously—then serious planning could begin." Controllers would have to use maneuvering thrusters to ease the satellites into circular orbits, where the shuttle could rendezvous with them, and to brake their rapid spins. Also, NASA would have to design special grappling hooks to snare the satellites, which have no pins for the robot arm to grab on to.

Challenger is scheduled to fly again on April 4, the shortest turnaround time yet for the shuttle. Not having to transport the orbiter from California, where most previous flights have landed, will give NASA an extra week to prepare for its April date with Solar Max.

PART II: THE RESCUE

NEXT STOP: SOLAR MAX

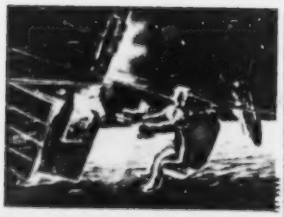
In April, five astronauts will make a dramatic house call to a sick satellite, wrestle it to rest, and perform electronic surgery in space.

Davy Crockett and Paul "Bear" Bryant both won their reputations wrestling bears, but early in April astronaut George Nelson, 33, should go them one better by engaging in the space-age equivalent: wrestling a 5,000-pound satellite orbiting 305 miles above the earth. Armed with only the microcomputer brain and tiny nitrogen thrusters of his manned maneuvering unit—the rocket backpack tested successfully on *Challenger's* February flight—Nelson will try to still a wobbling, disabled space observatory known as the Solar Maximum Mission, so that it can be grabbed by the shuttle's robot arm. Nelson's encounter will be the highlight of the most dramatic space mission ever planned: the capture and repair of a satellite.

The designers of Solar Max, as it is affectionately known, had no such spectaculars in mind when they launched it on Valentine's Day 1980 with a battery of instruments to photograph and analyze the mysterious storms and explosions that wrack the outer layers of the sun every eleven years, when the number of sunspots, which rises and falls cyclically, reaches its crest. This activity—called the solar maximum—lasts two or three years thereafter; the sun shoots out particles more frequently and savagely than usual, bombarding the solar system and disrupting communications on earth.

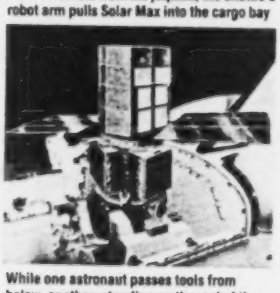
Solar Max was the first satellite built with standardized, easily replaceable plug-in modules containing circuitry to perform such chores as controlling electrical power and keeping the craft and its instruments pointed in the right direction. In anticipation of the shuttle, which did not venture into space until 1981, the satellite was also equipped with grapoling pins for the shuttle arm to hook onto.

Scientists had planned to bring Solar Max back to earth in 1986, say, after its mission was completed, but after only eight months a fuse blew in the satellite's pointing system, leaving the $200 million spacecraft drifting aimlessly, and setting the stage for April's Buck Rogers heroics. The capture and repair have been practiced move by move, screw by screw, in underwater tanks, flight simulators, and, most recently, in space, when the crucial backpacks were tested.



Dodging the spinning solar panels, an astronaut moves in and prepares to latch onto a grappling pin on the side of Solar Max

After the astronaut has stabilized the satellite with bursts from his jetpack, the shuttle's robot arm pulls Solar Max into the cargo bay



While one astronaut passes tools from below, another, standing on the end of the robot arm, begins working on Solar Max

It should all become reality early in April, when a five-man crew led by Robert Crippen (who has already flown on two shuttle missions) is scheduled to blast into a 305-mile-high orbit, the highest the shuttle has yet flown. Along with Nelson and Crippen, 46, will be pilot Francis Scobee, 44, and mission specialists Terry Hart, 37, and James van Hoften, 39.

On its third day in space, *Challenger* will rendezvous with Solar Max, which is spinning slowly, at one sixth of a revolution per minute, its solar panels sweeping space like giant fan blades. While van Hoften watches from the cargo bay, Nelson, in his rocket backpack, will fly about 200 feet over to Solar Max, dodge the delicate, slowly rotating panels, and grab onto one of the grappling pins with the special adapter used in February's practice sessions. Then, by firing his backpack thrusters in the direction opposite from Solar Max's spin, he will halt the satellite's rotation. *Challenger* will approach closer, and Hart, operating the robot arm, will grab Solar Max. Nelson will let go and follow along, he and van Hoften ready to give a helpful nudge, as Hart sets the satellite down into a special cradle in the cargo bay.

Then Nelson will doff his backpack and both men will pick up their tool kits. Riding the end of the robot arm as he would a cherry picker, to get around the 18-foot-high satellite, van Hoften will replace the 500-pound module containing the broken pointing system with a new one. That is the easy part. NASA would also like the astronauts to replace the failed electronic innards of Solar Max's coronagraph, a camera that photographs the hot, tenuous, outer layer of the sun. But the coronagraph's electronics were not designed to be replaced in space. To get at them, van Hoften and Nelson will have to cut Solar Max's insulation, undo 22 little screws, unplug connectors, and cut wires, and then reconnect them all—while wearing bulky spacesuit gloves. That task, in addition to the capture effort, is too much to do in one six-hour outing.

Most of the coronagraph work will be done during a second space walk, on the fifth day. In between space walks, while the repairmen rest, *Challenger* will climb yet higher, to 330 miles, in order to get the heavy satellite above the outer fringes of the atmosphere—and thus clear of atmospheric drag—when it is finally released. After Solar Max scientists at the Goddard Space Flight Center in Maryland have certified the satellite's health, Hart will lift it back out of the cargo bay on the sixth day and cast it loose to begin scientific life again. The shuttle will cruise near by for about eight hours to make sure Solar Max is back in good health before the crew begins making preparations to come home.

What if the astronauts are unable to fix Solar Max? They will stow it in *Challenger's* cargo bay and bring it back to earth to be repaired and returned to orbit on a later shuttle mission. Despite this contingency plan, NASA thinks that the ailing observatory will need only outpatient care. *D. O.*

PART III: THE SPACE STATION

WELCOME TO THE COSMIC MOTEL

NASA plans to build a permanent outpost in the heavens as a home for astronauts, a lab for scientists, and a factory for space industry

BY NATALIE ANGIER

Years and years from now, when people can vacation in a lunar lodge, mine the moons of Jupiter for minerals, and wear silver jumpsuits to work, they will look back on the twentieth century and try to date the beginning of the space age. Some, no doubt, will point to Sputnik, Yuri Gagarin, and John Glenn. Others will recite Neil Armstrong's quote about small and giant steps. But at least a few will cast their votes for the moment when Bruce McCandless levitated out of the space shuttle like a magician's assistant, spinning and rolling as gracefully as a young Rudolf Nureyev. Freed of the tethers that had chained astronauts to their craft in the past, McCandless was at home in space. All he lacked was the house.

If Ronald Reagan has his way with Congress, such a house will be built by 1992. In his State of the Union speech last January, the President announced that he would order NASA to begin construction of a manned space station—a project that will cost at least $8 billion. "This nation is at its best when it dares to be great," he declared. "We can follow our dreams to distant stars, living and working for peaceful economic and scientific gains." By committing the country to a major space-capade in what is not coincidentally an election year, the oldest president ever allied himself with the youngest ever; Reagan's address sounded distinctly like John Kennedy's "land a man on the moon" speech of two decades ago.

At space centers around the country, corks popped and NASA staffers hugged each other: the announcement had ended agency head James Beggs's three-year plea for space station dollars. By NASA's reckoning, the station is the next evolutionary step in space science and exploration. Through its portals, the agency insists, manned spacecraft will depart for the moon or even Mars at a fraction of the cost of launching such expeditions from earth, and technicians will haul in and repair wayward satellites. In its compartments, astronauts and scientists will conduct important experiments in fields ranging from astronomy to chemistry; unfettered by the earth's gravity, industry will manufacture better computer chips and concoct new chemicals. Industry had other reasons to cheer. Boeing, Rockwell, and the other aerospace companies hope to benefit from fat contracts that the space station project will send their way.

Yet not everybody is celebrating. Why a manned space station? many scientists wonder. What in the world are we going to do with it? Think of how many fellowships $8 billion would buy, or telescopes, or nuclear magnetic resonators. "There's plenty of study and experimentation to do before we need [the space station]," said Victor Reis, former assistant director of the White House Office of Science and Technology. "What corporation would spend billions to construct a plant before either the manufacturing technology or the market were even established?" Even the proponents of high-tech wizardry at the Pentagon see no need for a space station. Still, Congress is likely to approve the initial $150 million requested for 1985, which will enable NASA to settle on the most viable blueprint.

The basic design is set: the station must include one living and dining module—called the "habitat"—one or two intercon-

Reported by Sue Butler Hannifin and Geoffrey Leavenworth

nected laboratories, a factory, a storage center, and a sort of garage, where the shuttle can dock. Solar panels will provide the power. Within these specifications, however, the possible configurations are nearly endless. Now comes the hard job of deciding on one that might work. If all goes well, construction will begin in 1987. Components will be hauled about 250 miles above the earth in a space shuttle's cargo bay, and then pieced together, like a giant Lego set, by the astronauts. The final component should be snapped into place just in time for the 500th anniversary of Columbus's discovery of America, at which point even today's grumpiest scientists and Pentagon officials are likely to find ways to put the station to use. "My suspicion is that the space station is like the telephone," says Gerald Griffin, director of the Johnson Space Center. "No one thought they would need it when it was first invented, but once it was developed, everyone found they couldn't get by without it."

The notion of a manned space station is not new. More than a century ago, the Boston clergyman Edward Everett Hale described in detail how a huge brick sphere could be launched into global orbit, to guide sailors lost at sea. Writing for *Collier's* magazine in 1952, the great rocket designer Wernher von Braun declared that "scientists and engineers know how to build a station in space that would circle the earth 1,075 miles up. The job would take ten years and cost twice as much as the atom bomb"—or $4 billion (in 1952 dollars).

In fact, America has already experimented with a space station of sorts. In 1973, NASA launched Skylab, a cigar-shaped craft about the size of a three-bedroom house. Trios of astronauts spent up to three months at a stretch working there, and though most of the news was eclipsed by Watergate, the scientific results were impressive: x-ray photographs taken of the sun revolutionized theories about the corona and solar wind, while medical experiments revealed much about the body's reactions to weightlessness.

Skylab crashed to earth prematurely in 1979, when particles from solar storms caused the atmosphere to expand into its path, decaying its orbit. But even if Skylab had remained aloft longer, it would not have been enough to sate the imagination of NASA engineers, who felt that a permanent station in space was the logical next step after the moon landings. Designers proposed ever-grander schemes. Original plans for a station housing twelve-man crews were expanded to provide for 50 or even 100 people, including mess attendants, storekeepers, a barber, a chaplain, and a psychiatrist. Crew members would work eight-hour days—Skylab and shuttle astronauts put in twelve-hour shifts—after which they would retire to the gymnasium for a workout, or to their private cubicles, where they could read or watch television. Rooms would be decorated in restful, easy-on-the-eye colors—light blue or camel—and lighting changes would simulate day and night. A reusable vehicle would shuttle the astronauts back and forth from the earth.

But Vietnam caught up with the dreamers. The government decided that it needed only the shuttle half of the proposal (the half the Pentagon wanted), and vetoed the notion of building any station at all, let alone an entire suburban outpost. NASA did not abandon its hopes, though; like a good Zen master, it was prepared to wait as long as it had to.

Beggs and his assistants never flagged in their campaign for the space station. They toured the country, lecturing about the space station to aerospace and engineering groups and periodically discussing it with Reagan or his aides. If the manned space station seemed impractical, then NASA was prepared to build an unmanned platform, which could be converted later: the important thing was to put some permanent hardware up there. Many times it looked as though the President was almost convinced. When he showed up at a shuttle landing in the summer of 1982 to give a "Welcome home, astronauts" speech, many people thought he would use the occasion to give the space station a green light. But Reagan was noncommittal. His science adviser, George Keyworth, remained opposed to the space station, insisting as recently as a year ago that it "would be a big step backward."

Nobody is quite sure when or why the big change of heart occurred. Some think that Reagan took his first serious look at the space station proposals last winter, when former astronaut John Glenn was considered the biggest threat to his re-election. In June 1983, while addressing a group of mechanical and automotive engineers, Keyworth pulled an unabashed about-face, saying that a space station was a good idea, but not enough: "A space station is only an intermediate step in a more ambitious goal of exploring the nearby solar system." Perhaps the most decisive factor, though, was a report published in December by the congressional Office of Technology Assessment, which has this unsettling message to convey: "Soviet commitment to a permanent human presence in space contrasts with the absence of long-term U.S. goals." In their plodding, bearish fashion, it seems, the Soviets are pulling ahead in "space habitation"; they

SPACE may soon use space platforms to launch manned ventures to other planets, or even the moon—an orb heretofore under the stewardship of the United States. Spurred by the adrenaline of competition, Reagan decided to move. One amusing story has it that when he told the penny-pinchers at the Office of Management and Budget of his intention to authorize the project, David Stockman kindly reminded him of the deficit. Reagan replied with a grin, "Imagine what would have happened if guys like you had interfered with Columbus asking Queen Isabella and King Ferdinand to help him go to the new world."

After brief sparring between Houston's Johnson Space Center and the Marshall Space Flight Center in Huntsville, Alabama, for the lion's share of the project, Beggs appointed Houston the lead center. Nevertheless, all NASA's creative talent is sure to be tapped: the planned space station, while not as grandiose as earlier schemes, will still be enormous, and enormously complex.

The total package will house half a dozen people, weigh about 180,000 pounds, and be cozy enough inside for shirtsleeves. A central computer will control the climate in each section, ensuring that working spaces will be warmer, sleeping areas cooler, and the labs housing electronic equipment nippiest of all. Astronauts will stay for three to six months, dining on reasonably tasty cooked food rather than the "nutrition pill" (although NASA hopes some day to develop eatable algae that can be grown in space). There will be hot and cold water, and the air will be a mixture of oxygen and nitrogen, just as on earth. Because water and oxygen storage takes up so much room, Clarke Covington, manager of the space station project at the Johnson Center, advocates the development of a "closed-loop system," which is jargon for recycling the air and water on board. "For water, you take the humidity from the air, and purify urine and waste water with some kind of vapor distillation system," he explains. "The method would be initially expensive, but worth it over the long haul."

How to connect the modules has not yet been decided. The Marshall Center recommends arranging the pressurized cabins in a giant circle around a "multiple berthing adapter," which would serve as a kind of central lobby. Johnson engineers would string the sections together caterpillar-style.

Hovering in orbit near by would be one or more free-floating unmanned platforms. Telescopes and other delicate instruments could be put out there so that they are not disturbed by astronauts moving around in the station.

The most exciting invention to come out of the project so far is a new kind of solar cell. The space station will need up to 100 kilowatts of power—enough juice to supply the needs of a small neighborhood. If normal silicon cells were used, the array would have to expand over an area the size of several football fields. Instead, NASA has designed a cell made of gallium arsenide, which is more than twice as efficient as silicon in producing electricity; the new cells will convert about 23 per cent of the sun's rays into electricity, compared to the 10 per cent that Skylab's solar panels were able to harness. The final array of cells will be no bigger than 20,000 square feet—about half a football field.

Besides the stationary labs, NASA plans to have on board a couple of roaming gadgets now under development at the Marshall Center. One is the "orbital maneuvering vehicle" (OMV), an unmanned spacecraft only 15 feet wide and 3 feet high. Boosted by 6,700 pounds of propellant, the 10,500-pound OMV will fetch

broken satellites traveling as much as 1,500 miles above the earth and bring them back to the station for repairs. Another possible craft (not included in the present budget) is a manned "orbital transfer vehicle," which would allow an astronaut to visit a satellite wandering uselessly in the wrong orbit (like the Westar and Indonesian satellites launched by *Challenger* in February) and attach a propulsion system that would shove it into its proper path.

Apart from rescuing the flubbed projects of past shuttle missions, how would the astronauts spend their days? NASA has a long list of possible activities. One lab on board will be devoted to animal and plant research, with facilities to house as many as four monkeys and 200 rats. Another room will be set up for laser, electronic, and similar high technology experiments. Says Dave Wensley, chief engineer of the space station at McDonnell Douglas in Huntington Beach, California, "There are certain things in science for which having a man available is a distinct advantage. On Skylab, the astronauts made more discoveries about the earth's oceans than were made by any other means at that time."

NASA also hopes that industry will invest in the station. McDonnell Douglas, together with Johnson & Johnson, plans to produce rare drugs using the technique of electrophoresis in a free-flying module that may or may not link up with the station. In electrophoresis, a current of charged particles is passed through a moving solution of protein, blood serum, or a similarly complex mixture in order to separate the different compounds present according to their electrical properties. Terrestrial gravity severely limits the efficiency of this sifting, as well as the purity of the resulting constituents; chemicals tend to spread and smear together. In the weightlessness of an orbiting space station, an electric current can separate compounds 700 times faster and with a fourfold jump in purity. The two giant corporations already have tested the idea aboard the space shuttle, and found that it has great potential. "We can speed up research drastically," says James Rose, director of Electrophoresis Operations in Space (EOS) at McDonnell Douglas. "For every new chemical created on earth, we could make five in space." Among the pharmaceutical possibilities: insulin, interferon, and various growth hormones.

The space agency has other suggestions for industry: optical fiber production, laser communications testing, ultra-pure computer chip manufacturing, and much more. Investing in space is serious business though; McDonnell Douglas will not discuss figures, but the EOS will certainly cost well into the multimillion-dollar range—quite a sum for companies that have been reluctant to renovate existing plants on earth. For now, even the richest corporations are taking a "wait and see" approach.

It is because of the uncertainties surrounding the manned space station that so many scientists oppose it. James Van Allen of the University of Iowa, who discovered the radiation belts around the earth, pooh-poohed the projects proposed for station-based astronauts as "busywork." Von Eshleman, director of Stanford's Center for Radar Astronomy, insists that "technological thrust is better served by unmanned space exploration than by manned." Last year, a team of 40 students and four professors at Stanford conceived an idea called the Pleiades Project, a flotilla of unmanned platforms bearing diverse scientific experiments, which would cost a fraction of NASA's plan. Moans Eshleman, "When you have a major emphasis like a manned space station, it consumes so much of the major funding that other sciences suffer."

Secretary of Defense Caspar Weinberger remains a staunch foe of the space station, manned or otherwise; he is afraid that it will pull money away from other NASA projects crucial to the Defense Department. Days after the State of the Union address, he wrote a letter to Beggs restating his opposition to the project. Ironically, Weinberger's opposition may aid NASA's cause: the space station will not bear the stigma of being part of the huge defense budget.

Meanwhile, Reagan is sending Beggs on a diplomatic tour of Europe and Japan, in an effort to drum up foreign support—and money—for the space station. If all goes well over the next few years, the men and women who now venture into the cosmos like nervous tourists to an alien land will be able to kick off their shoes and make themselves at home in their motel in the sky.

PART IV: THE FUTURE

THE LAST FRONTIER

This is not an era of bold dreams or imaginative causes. Today, in our hopeful moods, we are content to try to preserve the world rather than transform it—or rush madly to the far ends of it, propelled by the sheer romantic exuberance of exploration. *Star Trek*, after all, was a product of the Sixties, Captain Kirk a Kennedy reaching for the stars. We are grown up now, and practical.

In February, however, we were transfixed by images from space that seemed out of a dream: Bruce McCandless, launched slow-motion into the void, a human satellite, suspended like a white god above the blue curve of the earth. We had seen those images before only in movies like *2001*, or in our schoolboy imaginations when we read science fiction. Many of us who report on space have been holding our breath for the past few years as the space program rose from the pit of inactivity that characterized the years after the last Apollo mission, half expecting the whole enterprise to sink back again. But the shuttle program has flourished, and science journalists suddenly find themselves commuting almost monthly to Houston, and thinking about installing permanent telephone lines at the Kennedy Space Center. The future has arrived almost unnoticed. Shuttles do not yet fly as often or as profitably as NASA wants, but it no longer seems absurd to think that human beings could revisit the moon or set foot on Mars by the end of the century.

So now it is time for the next step, a space station, an orbital waiting room for the deep-space bus, a permanent microgravity playpen for science, a platform from which to look over the health of Spaceship Earth. That is not a big dream; it is no call to arms like a manned Mars mission or a moon colony, each of which would cost tens of billions. The station's $8 billion price tag—a tenth of a per cent of the federal budget for eight years—is not likely to be felt by taxpayers beleaguered with a $1.5 trillion weapons build-up.

In fact, the amazing thing about NASA's proposed space station is how sensible and modest an idea it is. The American space program has in the past been characterized by spurts of grandiose ambition, followed by the distressing slashes of budget knives, and depressing slowdowns by each new administration, perhaps because we have never decided what space is for. Is it for Cold War competition? Is it for science?

Americans view space differently, and less practically, from their Soviet counterparts, who have forged ahead slowly but relentlessly. That may be because space is the extension of the roamings of a restless people—a frontier, if you like. To Americans, the future has always been represented by someplace to go, the next California or Alaska. Space is the connection between our past and our future—a connection brilliantly evoked by the cowboy test pilots portrayed in *The Right Stuff*. We cheer the Voyager images of Saturn and the Apollo views of white-suited men shuffling in the lunar dust because we are used to looking at godforsaken wilderness and imagining where the tennis courts will go. We have lurched rambunctiously upward and outward with our hearts as much as with our heads. But now we are grown-ups, ready for an aluminum-covered cottage in the sky with a silicon roof.

Still, there are critics. Some think a space station is boring, not ambitious enough to stir the American people. Others say it is too ambitious and expensive in a time of $200 billion deficits. Some of the doubters are space scientists, whose reservations were summarized in a report of the National Academy of Sciences that stated that there was no immediate scientific need for a space station. They fear that the house in the sky could, on balance, be harmful to science. For example, NASA-supported science projects designed to take advantage of the space platform would be hostage to delays in its development. That is what happened when the space shuttle was being built; spacecraft intended for launch by the shuttle languished as the shuttle program fell months and then years behind, and planetary exploration nearly died. Scientists also fear that money for the station will be diverted from scientific endeavors, as it was during the shuttle era.

NASA claims that it will not put scientists through the wringer again. The same 1985 budget that allots $150 million for the space station also includes funds for a new Mars probe and an upper-atmospheric research satellite, but it also slashes $5 million from money for analysis of previous missions. That has led some scientists to complain that the squeeze may already be on. It would be a shame to pay for the space house by selling the solar system.

But there is not enough money in planetary exploration to pay for a space station even if all the probes were canceled. Conversely, the bulk of the money saved by not building a space station would not be spent on science (or on mass transit or education, for that matter).

Unlike the shuttle, the space stations being studied involve little unpredictable new technology, no expensive problem children like delicate thermal tiles that chip and fall off, or fancy new rocket engines. The essence of a space station module was actually flown in space last December. It was called Spacelab, a pressurized scientific laboratory that sits in the cargo bay of the shuttle. To become an independent space station, Spacelab needs little more than a solar array for electrical power and a small rocket engine for maneuvering. So there should be little occasion, or excuse, for the kind of overruns that ballooned the shuttle's cost. If they do occur, help for science may also come from Congress. While there is congressional support for the space station, accord-

ing to surveys by space lobbies, there is even more support for the robot planetary expeditions that have so changed our view of the solar system.

Who benefits from the space station? NASA and the President have emphasized the commercial opportunities for drug and materials processing in weightlessness, but it is too soon to know which, if any, of those processes will turn a profit. The space station is a venture capital investment, in the tradition of the land giveaways of the last century. Judging by the number of young MBAs forming space corporations, the action need not be limited to the multinationals.

There is a danger in being too practical in space. If we are so cautious that we demand an accounting in advance, then our potential is limited by our own lack of imagination. What good is a future that we can predict? In 1971, a spacecraft named Mariner 9 slipped into orbit around Mars and found the planet covered by a ferocious dust storm that had cooled its surface and heated its upper atmosphere. That observation led planetary scientists to investigate what could happen under similiar conditions on earth. They concluded last fall that the smoke from burning cities after a nuclear war could block sunlight, bring about a "nuclear winter," and freeze mankind and perhaps all life right off the earth. This finding, when it sinks in, could help alter our attitudes about war and, maybe, save the race from extinction—if the race were to start behaving rationally. It is hard to think of any more practical benefit. Federal budget cutters might note that a congressional study showing that the technological and economic benefits spawned by NASA expenditures have outweighed their costs by 14 to one.

In other words, space is (in the language of the Eighties) a terrific investment. And it is the space program itself that needs the space station, as an interim payment on bigger dreams. When pioneers leave for the moon, Mars, or beyond, they will ride covered wagons assembled in orbit. Dick Tracy's two-way wrist radios will be fiction no more when there are communications satellites with antennas the size of football fields in geosynchronous orbits—assembled in low orbit and then boosted higher.

Most Americans will never go into space, but their children and children's children will. The space program has become a kind of national monument, our bequest to future generations. It is our acknowledgment that we are wards of the universe, that our cause and our destiny are bigger than ourselves. We have gleaned only a few insignificant structural and chemical details of the mysterious predicament in which we find ourselves: wandering about in individual bodies in a universe of lights, of starry islands all racing apart. We know that those lights in the sky are real places, future theaters in which we may play unknown roles. In this moment, poised between apocalypse and apotheosis, 80 years after we learned to fly, and 5,000 years after we learned to write, the future is still up for grabs.

The world can probably exist without giant communications satellites, without Mars rocks in museums, and without foamed aluminum made in space, but we cannot live without a sense of that future. Only a few great and rich nations have the luxury and duty of creating the future; it is part of the dues of empire. A thousand years from now, when the centers of learning and wealth have shifted elsewhere, perhaps to China or to the moon, we, along with the Soviet Union, will be judged on our stewardship of the earth and of mankind's dreams. Ours is the generation to which it has fallen to take the first steps outward from earth. Perhaps it will be said that, in the brief time allotted to us, we ran as fast and reached as high as we could. *D. O.*

THE AMERICAN JOURNAL OF PSYCHIATRY

The Journey Out and In: Psychiatry and Space Exploration

Patricia Santy, M.D.

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Although psychiatric issues have in theory always been considered important in space biomedical research, specific research into these issues has been severely limited because of other priorities that were more pertinent to the technological development of space flight capacity. As the technical and physical aspects of space flight become more routine, the psychological issues should take on increasing importance. The author reviews the U.S. and U.S.S.R. research in aerospace medicine that is relevant to psychiatry and suggests ways to expand psychiatry's clinical and research usefulness in future space exploration efforts.

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In our lifetimes we shall probably see the beginnings of the colonization of space. I have no doubt that such colonization would mark the most important series of events in the history of mankind. As a psychiatrist, as well as a scientist, I believe that the ultimate success or failure of this great human endeavor will hinge considerably on many psychiatric factors. Whether man as a living organism can survive the formidable environmental dangers of space seems to have been answered affirmatively by the success of the manned space programs in the United States and the U.S.S.R. Whether man as a psychological entity can survive the transition from life on earth to life (or years) in the space environment remains unknown. A mass of physiological data has been accumulated, but many basic psychological questions remain unanswered.

There are several reasons why the psychiatric questions have not been answered, or even asked in some cases: 1) psychological questions were relatively unimportant in the early phases of the space program because the primary question was whether man could survive at all; 2) the length of time men spent in space and the size of the crews sent on various missions were limited, thereby limiting the type of psychological adjustment necessitated; and 3) the crew's privacy and comfort, which led to the crew's unwillingness to engage in psychological research, were given high priority in the early missions. Astronauts developed understandable suspicion of much of the medical and psychological activities that surrounded the early selection and flights, as described in Tom Wolfe's best seller *The Right Stuff* (1). The clinical psychiatrist, whose medical decisions have traditionally kept pilots grounded, has long been viewed with distrust by military pilots. Berry (2) commented in 1973, "We still know very little about the effects of the space environmental complex on personality and psychic well-being. These aspects of the human could prove to be the factors which limit the duration of space flight."

Now that the United States has entered a new phase in its space program—the shuttle—psychiatry must begin to address some of these crucial questions. In this paper I will review several areas of behavioral and psychophysiological research relating to space flight. I will then discuss models and methods of future psychiatric/psychophysiological research, and, lastly, I will speculate on two issues that relate to psychiatry and future space exploration.

CLINICAL ASPECTS

Astronaut Selection/Crew Selection

The bulk of clinical activity for psychiatry in the U.S. space program has been in the area of preselection aeromedical evaluations. As part of a team of physicians, psychiatrists have had considerable input into the astronaut selection process from the very beginning (2–15). As Kubis and McLaughlin (3) noted with the

Received May 26, 1982; revised Sept. 17, 1982; accepted Nov. 23, 1982. From the Department of Psychiatry, University of Wisconsin Medical School (Milwaukee). Address reprint requests to Dr. Santy, 950 North 12th St., Milwaukee, WI 53233.

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first group of seven astronauts, the psychological stability of the candidates was considered of primary importance during the final evaluation process.

In general, situations that require prediction of performance have led investigators to rely on psychiatrists because of their presumed expertise in human behavior. Traditionally, the military aviation psychiatrist has had the power to ground a pilot as "unfit for duty" because of a psychiatric disorder. Because an overt psychiatric disorder is rare among such a select group as astronaut candidates, the psychiatrist's role is most useful for those candidates whose motivations are "pathogenically overdetermined" but who show no current evidence of psychiatric disorder. Personality areas that seemed to relate to potential for successful mission accomplishment have been defined. In particular, the following areas were felt to be of importance in this predictive task: general emotional stability; high motivation and energy level; adequate "self" systems (positive self-concept, sense of adequacy, emotional control); and satisfactory and productive interpersonal relationships. It was felt that the appropriate motivation was for the candidate to be "mission-oriented" (9–11) rather than oriented toward personal achievement. All of these factors were then evaluated by psychiatric interview, psychological tests, and observation of performance under stress. Psychiatric ratings of the candidates for the Mercury mission closely matched the final selection ratings (15).

It is important to note that most of the literature has dealt with the Mercury, Gemini, Apollo, and Skylab astronaut selections. Although psychological tests and psychiatric interviews were conducted on candidates for the more recent Shuttle mission, it is unclear how great a part this information played in the final selection process, but we can assume it was not a trivial one. In addition, the early literature deals with selection among a relatively homogeneous group of individuals: all males, all career military pilots, and few bachelors. With the introduction of the scientist/astronaut candidate later in the Apollo program, a more heterogeneous group of individuals was selected. The motivations and personality of the pilot applicant group may be somewhat different from those of the scientist applicant group. Whether different psychological criteria were, or should be, used for the scientist/astronaut applicant as opposed to the pilot/astronaut applicant would be important to know. (We do know that different physical characteristics were required of the two groups, e.g., vision requirements.) The question of appropriate motivation for space missions, which is possibly an extension of the pilot's professional motivation (15), is not so clear for scientists. According to Perry (9), "As the complexity of motivations increases, so will the chances of their being neurotically overdetermined." There are, however, no "standard" personality types or ready-made guidelines to rely on in assessing psychological capabilities; all such assessments should be part of a more global assessment of each candidate's overall capabilities.

It is unclear what role (if any) psychiatry has played in actual crew selection, i.e., who will be on what mission. Psychiatrists could be extremely useful in this area in evaluating who works well with whom (especially since the number of crew members will increase on later Shuttle missions) and in the application of general group dynamics. Perry (8) has even suggested a psychiatric back-up procedure for every crew that will help deal with emotional problems which may arise in both the crew and their families before, during, and after missions.

In summary, then, the psychiatrist seems to have played an important role in the selection of astronauts. Evaluation of candidates' "psychological fitness" seems valid for selecting astronauts, as does evaluation of candidates' overall "fitness" and the compatibility of crews. The selection process remains an area where psychiatry can expand its clinical usefulness in future space exploration efforts.

Isolation/Confinement

Early in space research the problem of isolation and sensory deprivation was felt to be one of the more serious psychological issues. Numerous studies done on earth-bound isolated individuals and groups, such as submariners (16–21), Antarctic journeyers (17, 18, 22), and volunteers in simulated environments (23–30), reported remarkably consistent findings regarding man's response to isolation. Reported symptoms varied only slightly from study to study, and all studies recorded the following symptoms: boredom, restlessness, anxiety, sleep disturbances, somatic complaints, temporal and spatial disorientation, anger, and (most important), deficits in task performance over time. Furthermore, in studies of isolated groups of men (18, 19, 21), researchers had to take into account such factors as group and social influences, individual and leader roles, and individual personality coping mechanisms. For example, Gunderson (18) and Gunderson and Nelson (19) studied groups in isolated and remote Antarctic stations over several months and followed subjective evaluation by the men of their symptoms. By far the most common complaint was sleep disturbance (reported by 72% of the individuals), followed by depression, headache, irritability, and other somatic complaints. It was noted that all the symptoms increased over time. Even when such symptoms (especially depression and irritability) occur among only a few members of a small, isolated group, they could pose serious survival problems for the rest of the group under certain circumstances; thus it becomes essential to understand the etiology of the problem and to pose some methods for coping with it as a group. (These issues will be discussed further in the section on group interaction.) Consistent in all these group studies was evidence that group compatibility and performance typically declined over prolonged isolation. On the other hand, Earls (20), who studied submariner groups, was struck by "the relative absence of overtly

expressed hostility" on the part of the submariners. This conflict—between the individual's unwillingness to alienate the group (upon which one's individual survival depends) and the increasing and inevitable normal kinds of tension that must remain undischarged (no overt aggression)—can arise in any group situation. Often the unresolved conflict can lead to depression and somatic complaints.

Berry (2) pointed out that sensory deprivation/isolation issues have thus far proved to be nonproblems in space flight (in fact, the opposite, hyperarousal, has more often been the problem). It seems clear, however, that for long-duration, extended space missions manned by individuals with more heterogeneous personality styles, isolation issues will become increasingly relevant and will require further study.

Hyperarousal/Sensory Overload

Instead of men in space experiencing the expected sensory deprivation, it has become obvious that they experience overstimulation or "hyperarousal." Aitken (31) pointed out that such symptoms as insomnia and anorexia, of which many of the astronauts have complained, could be due to a physiologic state of hyperarousal. Normal excitement, intense work schedules, numerous tasks, and the absence of many temporal cues (night versus day) all probably contribute to this state. If the hyperarousal state is prolonged, such long-term effects as perceptual abnormalities, impairment of concentration, depersonalization, muscular incoordination, and overall deterioration of performance may occur. It has been pointed out that several U.S. missions were jeopardized by unusual and unexpected behavior on the part of the crew and that at least one cosmonaut was noted to have unexpected inefficiency in operating his controls and had to be landed early (31). Thus, it appears that sensory overload may be an important factor in short-duration missions, and both sensory overload and sensory deprivation/isolation may be factors in long-duration missions.

Group Interaction

I will look at group interaction issues separately, although some of the problems that arise in this area have already been alluded to in the isolation section. Since the beginning of manned flight, the trend has been to increase the number of persons on each mission. As space vehicles enlarge and personnel roles become more specialized, even larger crews will be necessary to carry out the many research and assigned practical tasks (32). To date, the largest number of men in space working together at one time has been on the Apollo-Soyuz mission, when five people were interacting (three Americans and two Russians) (33). Establishing a large space station for purposes of scientific investigation and support for manned interplanetary missions will require numerous individuals working in a close-knit, efficient team manner. Many of these individuals will have to be highly specialized; they are therefore more likely to come from culturally and scientifically heterogeneous backgrounds. Obviously, psychological compatibility and methods used to determine the selection of the crew will play a large role in the ability of such crews to perform efficiently. The Soviet space program has long recognized this as a problem; to a lesser extent, so has the U.S. program. From the beginning of training, cosmonaut candidates are subjected to the most grueling psychological tests, and the candidates are grouped according to compatibility (34). The Soviets also have the edge in duration studies of groups in space, although, again, it is not as likely that serious problems will arise in small groups of homogeneous cosmonauts who have similar military backgrounds, values, and mission goals.

A new dimension was added to the evaluation of group dynamics in space when the first woman astronaut was selected for the crew of the Challenger. When Valentina Tereshakova, the first woman in space, made her few orbits, she did not have to interact with any male fellow astronauts—she went up alone and was in space for only a short time. Shortly after the United States named its first woman to go up in space, the Soviets sent Svetlana Savitskaya into orbit to rendezvous with fellow cosmonauts in the Soyuz space station. Other than as a publicity stunt and possibly to "scoop" the United States, it is unclear why the Soviets did this, as their thinking on the subject of women in space is not as liberated as one might assume. "Women are more emotional and are upset easier," chief Soviet cosmonaut Lt. General Vladimir Shatalov and veteran cosmonaut Georgy Beregovoi suggested in a recent article (34). Also as far as is known to observers in the West, the U.S.S.R. is not actively training any women to be cosmonauts.

At any rate, the possible repercussions of adding women to space crews are immensely interesting from a psychological standpoint. Thus far, the consequence of adding women to crews has not been dealt with in group studies, which have been with all-male groups. The issue of sexuality, especially on long-duration missions such as an interplanetary one, is not trivial. No matter how well trained the crew is, there is reason to expect that such issues as sexual arousal, tension, and competition are just as likely to occur in space as they are in any earth-bound endeavor, and they present a potential hazard to the accomplishment of mission goals. Having astronauts who are married to each other fly on the same missions is one approach to reducing the issue (currently there are two married couples who are astronaut/mission specialists), but again there is no reason to believe that the same type of tensions may not develop.

One method of approaching the complexity of handling group problems in space could be to train astronauts in simple group dynamics. Perhaps entire crews could participate before their flights in an ongoing group process to help identify and resolve potential trouble areas and to learn problem-solving techniques,

before they arise in the more dangerous space environment. As a practical method, this would also give the astronauts a model for resolving in-flight hostilities and tensions that can lead to group-threatening behaviors and decrease crew performance (35, 36). Such a method would offer useful ways of discharging tension and anger and possibly of alleviating the symptoms of depression and the psychosomatic complaints reported in other isolated groups. Such a technique could be tested out in other groups, such as submariners, in addition to space crews.

It is relevant to note here that in spite of all the concern expressed in the United States early in the space movement about the psychological effects of space on the human organism, according to Bluth (34) the U.S. space program has never made a formal attempt to set up experiments and record behavioral reactions, nor has it used behavioral scientists in its training program. This is one area in which the Soviet Union clearly excels, if only in its willingness to study such problems. It is very clear that psychiatry can make valuable contributions in this area.

Finally, it is important to realize that new situations and environments have always caused alterations in traditional social structures. Men and women in space will be in situations no human beings have ever had to deal with before. Preformed, rigid social structures may severely hinder the processes of psychological and physical adaptation that will be essential to explore the universe. On the other hand, meaningful social and environmental structure is necessary to some degree for individual egos to cope with the space environment. We must avoid letting rigid cultural values and customs, especially in the area of sexual mores, prevent research in this area.

Man-Machine Interactions

Airplane manufacturers have long known the importance of designing efficient man-machine systems for their planes. Faulty design in this area can lead to lethal consequences. After years of research, the size, shape, and even placement of certain dials and instruments are now specified because it was discovered that optimal treatment of these factors increased the efficiency of the pilot's interaction with the airplane and therefore decreased error (37, pp. 128–156, 38–40). The problems of man-machine interaction—from the design of space ships and stations to the layout of systems within the space vessel—seem especially relevant for psychiatric investigation. Issues of habitability become extremely important in longer-duration space endeavors (41). Attention to environmental detail may be an important factor in helping astronaut crews deal with stress during long-duration missions.

Jones (41) discussed nine aspects of habitability that were first compiled by Johnson (42): 1) environment (including atmosphere, temperature, lighting, and radiation levels); 2) architecture (how the living space is arranged); 3) mobility, restraints, and equipment handling; 4) food (i.e., preparation and storage); 5) clothing; 6) personal hygiene (body waste collection, grooming); 7) housekeeping (refuse, cleaning, laundering); 8) communication (intravehicular only); and 9) off-duty activity provisions (exercise and entertainment). Other issues that I believe will be important on long-duration missions are continued communication between the crew and earth; allocation of space for individual mementos (e.g. pictures and items with sentimental attachment); time for off-duty creative activities, such as painting, writing, or gardening; and the option of being alone, i.e., space designed to allow individuals to be by themselves.

The National Aeronautics and Space Administration has long recognized the importance of habitability in determining astronaut morale. Food items, for example, are selected to meet the tastes of individual astronauts. Music is used to boost morale on the space missions (wake-up calls played by Mission Control are often selections of the crew's favorite music or humorous sketches). Humor plays an important part in keeping tensions low. For example, in submarines it has long been noted that the number of practical jokes tends to increase during the voyage and seems directly related to the build-up of tension. As mankind's efforts in space expand, these habitability factors are bound to become increasingly important. For instance, the psychological needs of the shuttle's passengers have been kept in mind during the design of its environment. The Soviets have also recognized their passengers' needs, and during their long-duration missions, cosmonauts reported much satisfaction with their gardening attempts in space—as both a recreational pursuit and as a practical solution to the problem of obtaining food in space. In the popular TV series *Star Trek*, the *USS Enterprise* offered its crew a gymnasium and a botanical garden with plants from the home planet, as well as an interfaith chapel.

Other aspects of man-machine interaction should also be studied. Advances in computer technology have major implications for the men and women whose lives may depend on the appropriate functioning of such machines. In the science fiction film *2001: A Space Odyssey*, a paranoid delusional computer began to kill off its human crew. But computers with personality are no longer just science fiction. As computers become more sophisticated (more "human"), human reaction to computers may become increasingly less predictable. Along these lines, a recent article in the *New York Times* (May 2, 1982) told about a factory worker in England who "fell in love" with the machine he operated and who became upset when the company transferred him away from it. In large part, the interaction between man and machine is what will make space exploration possible. The input of psychiatry into this area can obviously be of great value. For example, studies on the psychological response of humans to computers or to machines in general would potentially be a useful research area. In addition, studies that look at individuals whose lives are depen-

dent on machines (e.g., hemodialysis machines and pacemakers) and these individuals' interaction with and feelings toward the machines would be relevant. Studies on the variability of stress and response in different habitats would be extremely important in designing future space dwellings.

The goal of studying man-machine interactions is to maximize the ability of man to work and live in the space environment. Many of the factors that now impede our achieving this goal will ultimately be reduced to an understanding of the psychological issues in man-machine interactions.

PSYCHOPHYSIOLOGICAL STUDIES

Response to Stress

Physiological variables have been monitored since the early days of manned flight. The traditional vital signs (heart rate, blood pressure, respiration rate, and temperature) were monitored in every manned flight because there was concern as to man's physiological capacity to deal with the physical aspects of space flight—weightlessness, in particular (37, pp. 50–92, 43–45). Measuring physiologic responses to stress was a part of the selection procedure and provided baselines for comparison in flight. Several important facts soon became apparent: 1) there is a considerable difference between laboratory stress and operational stress; 2) individual physiological response to stressful situations varies considerably; 3) physiologic response is not predictive, particularly of actual (behavioral) response, although it is useful in understanding and monitoring an organism's adaptation to the stress; and 4) no single physiological parameter can adequately reflect how the organism is coping with the stress, i.e., the homeostatic balance of an individual (15, 44).

As Rose (46) pointed out, in general the "*psychological* relevance of the stimulus rather than the particular physical stressors to which they were exposed has the most effect on the physiological response." Individual physiological response to stress has been measured in astronauts by breaking down the stress into four areas: 1) rest (normal, baseline), 2) anticipation, 3) stress, and 4) recovery (47). The study of the anticipation phase of stress application proved extremely useful in differentiating the emotional component aspect of the stress. In many situations the astronauts were found to have a greater physiological response during this phase than during the actual flight. This again points to the fact that individual response will vary greatly and will depend considerably on the individual's personal history, which may contribute a high degree of emotional loading to the response.

In addition to measuring the astronauts' vital signs, investigators of the early Mercury and Gemini missions determined the astronauts' levels of catecholamines (epinephrine, norepinephrine, and their metabolites) and 17-hydroxycorticosteroids excreted in urine. Epinephrine and norepinephrine are extremely sensitive measures for a wide variety of emotional stimuli. Epinephrine secretion is felt to be associated with situations characterized by novelty and unpredictability and seems to reflect the anxiety of a situation. When the situation is mastered, levels of epinephrine fall. On the other hand, norepinephrine secretion seems to reflect the amount of "attention-demandingness" or effort associated with a given task or the physical effort (46, 48–57). Technical problems abound in the measurement of urinary excretion of the catecholamines, and wide individual variability is found. Other parameters measured in the Apollo and Skylab missions included plasma cortisol and ACTH, as well as 24-hour urinary cortisol, growth hormone, and thyroid function (including free T_4). As one might expect, the astronauts' urinary epinephrine levels stayed relatively stable while they were in flight but increased before and after flight. Norepinephrine was more variable than epinephrine, but generally it seemed to increase at times during and after the mission. The astronauts' plasma cortisol levels increased substantially, and ACTH levels decreased throughout the Apollo and Skylab missions. The astronauts' 24-hour urinary cortisol levels increased substantially on all missions. Levels of free T_4 were found to be increased after the flight, and there was a modest increase in thyrotropin levels during flight. Growth hormone levels varied, but there was a noticeable increase in these levels during the first days of each mission and the first few days after recovery. All variables returned to baseline shortly after completion of each mission, and some returned to baseline during the mission, suggesting that adequate adaptation to the stress had occurred. The general rule seems to be that endocrine responses in flight extinguish as adaptation occurs (58–67).

Coping responses, or how individuals avoid being stressed when exposed to threatening environmental situations, are of special interest to the psychiatrist. Researchers (68) found that individual psychological defenses, such as isolation and denial, resulted in subjects' low cortisol secretion before a stressful event compared with subjects who were overtly distressed before the event. Thus, a defense may be effective physiologically but maladaptive psychologically, and it becomes an even greater threat to the organism. For example, women who had breast tumor biopsies and who denied the situation had low cortisol levels; however, because these women had waited much longer before coming to medical attention than women who feared the situation and immediately sought help, they put their lives at greater risk. In the same way, defensive structures in future space explorers may be vitally important; they may be more important than the explorers' physiologic response to stress. What seems to be missing from all the physiological data that have been accumulated are the concomitant behavioral correlates that would give the data more meaning.

The administrators of the Soviet space program have

always rated highly the behavioral aspects of space flight, and they have incorporated behavioral ideas into the cosmonauts' training program for the purpose of increasing individual stress tolerance. Reportedly, they put their cosmonauts through "live" hazardous environmental tasks (i.e., survival in a hostile climate) as part of training. Their purpose is to train cosmonauts to adapt psychologically to highly stressful situations. In fact, their entire training approach is behavioral and based on the so-called information theory of emotions (69, 70). This theory holds that the degree of emotional stress (E) is related to motivation (M) and information (I) by the following formula:

$$E = -M\,(I_n - I_r)$$

where I_n represents the information the subject needs in order to successfully negotiate a difficulty, and I_r is the amount of information the subject actually has or is able to receive. Although this is clearly a simplistic way of evaluating such complex phenomena, it has been surprisingly useful to the Soviets. They have, in fact, focused almost exclusively on the term $I_n - I_r$; they have tried to cognitively prepare their cosmonauts for every conceivable stress, thereby increasing I_r and reducing the term to zero (no emotional stress experienced) or to a negative number (only positive emotion experienced). Motivation, however, is also an important factor and deserves more recognition in research efforts. The M term includes such factors as defense structure, personality type, and coping mechanisms. Furthermore, because it seems likely that space will provide the human organism with environments and situations never before encountered in mankind's experience, the $I_n - I_r$ term may never completely approach zero, and the M term may need clarification and expansion.

Wherry (71) suggested a model for studying psychological stress, and Sells (32) has evaluated various terrestrial systems that could be used to study the stress and coping aspects of space flight. The shuttle offers a remarkable opportunity for behavioral scientists to do studies of men and women in actual space conditions.

Biological Rhythms

Psychophysiologic aspects of the sleep/wakefulness cycle, or circadian cycle, seem to be of particular importance in space flight (72, 73). Many physiological markers are rhythmic and affected by the physical cycle of day and night. (These include EEG, body temperature, hormonal variations, and immune variations.) The normal physiological time requirement for sleep appears to be about 8 of every 24 hours. Numerous studies have shown that attempts to ignore the need for sleep results in neurotic and possibly psychotic disturbances, including hallucinations and delusions. Air travelers moving through different time zones have aptly demonstrated the difficulty encountered in trying to "reset" this biological clock (74). It is possible, however, to change these rhythms over time (it usually takes 7–14 days, which is probably due to the slowness of response of such biochemical indices as cortisol levels) (75). Biological rhythms are reset when one changes from day to night work or even from a 24-hour work cycle to a 12-hour one. The desynchronization that occurs during such times may play a role in sleep disturbances, dysphoria, mood shifts, and gastrointestinal disturbances. All these symptoms have been reported in people during the biological readjusting or "resynchronization" (76, 77).

Our understanding of the underlying mechanisms of biological rhythms is still limited, but environmental cues seem to be an important factor in the cycling process (e.g., dark and light). In space, there are no environmental cues because the rotation of the earth and its day/night cycle are not observable. Natural time references, therefore, are absent. Studies with submariners indicate that, if clocks remain unchanged in the submarine, the men's diurnal cycles will remain undisturbed by the lack of outside cues. Likewise, it has been found that astronauts tend to stay on the same rhythm as their site of origin (72, 78). Obviously, earth time zones have little meaning for the orbiting space ship, as it passes through each zone in only a few minutes. Work/rest periods for astronauts will be dependent on their internal biological clocks. Studies in closed-cabin environments show that, without environmental cues, 5 hours of sleep and occasional catnaps during the work day seem to be sufficient for the inhabitants. Fatigue and increasing proneness to error were noted when this cycle was disturbed (78).

In recent years there has been an increasing emphasis on biological rhythms and their importance in psychiatry (79–81). The reality of time is part of the structure of the human organism. In addition to performance studies (79), which show that specific performance tasks seem to peak at different times depending on the skill required, studies of desynchronization have found that this factor plays a role in the etiology of depression, medical illness, and an individual's response to stress.

Although the human organism has proved to be extremely adaptable and capable of resynchronization over a period of time, it is unknown how far this adaptability extends. For example, will humans be able to colonize planets in other star systems—or even travel to those planets—if the biological rhythms established in our course of phylogeny on this planet are not compatible with voyages and life outside the sphere of terrestrial influence? Strughold (72) commented, "The physiological clock, manifested in terrestrial circadian rhythmicity, will play an important role in health and performance in man's conquest of space. . . . Its study under non-terrestrial cosmic conditions may shed some light upon the true nature of the biorhythmic phenomenon."

Psychophysiological Monitoring of Man in Space

From a practical point of view, the physiological monitoring of man in space is a great deal easier than psychological monitoring. Future space flights will continue to provide scientists with physiological data in areas pertinent to psychiatry. Data from studies of the hormonal and fluid/electrolyte status of astronauts will be essential to acquire on long-duration missions. EEG telemetry in the Gemini and Apollo flights proved to be a useful and practical method of monitoring sleep/alertness states (82–89). All these data are helpful in planning long-duration missions (89). There are many methods available for analyzing the physiological and biochemical responses of man to the space environment; however, behaviorally, there is a relative lack of pertinent research planning and information, especially information that can help to integrate the physiological data with actual behavioral changes. The psychiatrist is specially trained to integrate behavioral and physiological aspects of the human organism. As missions expand in length of time and number of crew, psychiatry's mission support responsibilities will need to expand into ongoing projects and in-flight support and research. In other sections of this paper it has been suggested that psychiatry can offer substantial expertise in many aspects of medical support for space flight. In addition, the psychological monitoring of humans in space requires that behavioral scientists should be part of the crew in order to conduct continuing research into man's psychological adaptation to space exploration. Astronauts have routinely reported on subjective experiences and have kept detailed logs during the missions, but these data must be considered only the beginning of behavioral research. Trained observers and researchers might provide even more reliable information and insights. The psychiatrist does not have to be considered a threat to the rest of the crew or as someone "invading the privacy" of crew members. If psychiatrists and behavioral scientists can be integrated into the structure of the crew in a manner similar to other medical professionals, an understanding by the rest of the space team of what psychiatry can offer will be obvious, and behavioral research will then come to be as acceptable as any of the other types of research that are carried out in space.

One possibility is to involve psychologically trained mission specialists in making more detailed and ongoing recordings of the astronauts' emotional responses to various positive and negative stresses in space (e.g., contacts with family members, recreational activities, response to unexpected problems). To further amplify the astronauts' responses, brief psychological tests could be administered at specific times. As part of the crew, such mission specialists may provide valuable data about crew interaction and interpersonal conflict resolution in the space environment, as well as valuable insight into man's psychological adaptation to the hostile environment of space.

SPECULATIVE ASPECTS

There may be many other opportunities for psychiatric input into the space exploration effort over the next 25 or more years. At the risk of sounding like the author of a science fiction story, I would like to suggest some areas of research that are purely speculative at this point but in which psychiatry may play an important role. The first area is an extraterrestrial psychology. A considerable amount of money has been spent and numerous volumes written by reputable scientists on the search for extraterrestrial intelligence (SETI). The field of exobiology has existed for many years and has grown considerably since it was first speculated that life in the universe may be based on an element other than carbon, e.g., silicon. Only science fiction writers have made attempts to speculate on the differing psychologies that such biologically alien beings might have. If these scientists are correct and the probability is high that intelligent life outside of our own exists, the problem of communicating with and understanding such beings may become imperative. The scope of the problem is tremendous, not only in speculating how the different biology has affected the alien psychological development (which would certainly lead to a better understanding of the interaction among biology, psychology, and the environment in living organisms), but also in studying human response to the potentially infinite number of forms such life might take.

A second and much more relevant area that also lies within psychiatry's realm is in understanding the "psychological evolution" of the human species. Niederland has touched on this fascinating problem in his writing on psychogeography (90–93). The problem involves nothing less than the concept of separation/individuation of our species from this planet, Mother Earth. What symbolism and fantasies lead individuals to go beyond their present horizons? Space exploration and the colonization of space by humankind offers a unique opportunity to study the motivation of our species as a whole. During the last great expansion of mankind, the westward movement (first to the New World, then within the New World to the American West, and now to space), psychiatry was a newly emerging discipline and perhaps was not yet ready to tackle such a task. Space exploration is, after all, the natural extension of an ongoing process that has enveloped mankind ever since evolution began on our planet.

There are many areas in which the clinical and research expertise of psychiatry may prove essential for the success of a manned space effort. As Perry (15) noted in 1967, "It is as if the absence of reports concerning *man* (as a psychological entity) were a product of denial in the psychoanalytic sense of the term. If this be true, of course, it would only serve to underscore the importance for the place which psychiatry may eventually have in support of man's progressive explorations of space."

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By ROBERT SALKELD
Chairman, AIAA Space Systems Committee

INTERNATIONAL EARTH-ORBITAL RESEARCH HABITATS

Toward Men Permanently in Space

Before the end of this century, thousands of people from around the world can have lived and worked together in an Earth-orbital research "proto-colony" of several hundred inhabitants

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The Apollo program proved that people can perform effectively for many days in space, and its descendent project, Skylab, extended this demonstration to nearly three months. Last year the Russians surpassed Skylab, and they appear committed with their Salyut orbital station to establishing the permanent presence of people in space.[1] Historical data and trends in F-1 show that the USSR leads the world in total person-years in space, can continue to do so for at least a decade, and that by 1990 we may expect to see 50-100 people living and working in space continuously.

So it appears that permanent human occupancy will be a next major milestone in the conquest of space. The U.S./European Shuttle-Spacelab cooperative effort moves in this direction, though slower-paced than the Soviet work. Lower-cost space transportation needed to support permanent occupancy has been identified and its technologies are being pursued in both the U.S. and USSR.[2-4]

Much of the future space population will be engaged in extensions of research and technology already begun in connection with Skylab, Salyut, Shuttle, Spacelab and other programs. Knowledge and knowhow from developments in space can benefit all peoples of the world. Many of these activities can be conducted most effectively on a cooperative integrated basis. *This suggests that all might gain greatly from an international Earth-orbital habitat for research and technology.*

An international spirit has always been part of the move into space and it is growing. From modern beginnings in the writings of Poe and Verne through setting of the technical base by Tsiolkowsky, Goddard, Esnault-Pelterie, and Oberth, the intellectual roots of space exploration have been diverse. The same is true of practical milestones. Goddard launched the first liquid rocket in 1926, the V-2 flew in Germany in 1942, the first Earth-satellite and first spacemen lifted off from the Soviet Union in 1957 and 1961, respectively, and the first men, Americans, walked the Moon in 1969. Direct USSR-U.S. cooperation in manned space operations began with the Apollo-Soyuz Test Project (ASTP) in 1976. Salyut has flown with international crews, as will Shuttle and Spacelab.

The International Astronautical Federation (IAF) was formed in 1950, Intelsat in 1964, and the European Space Agency (ESA) in 1975. At least a dozen other international space organizations,

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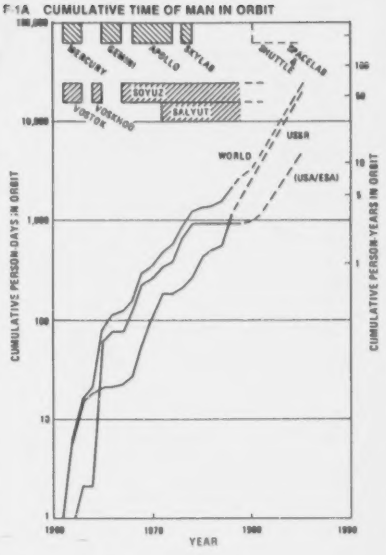
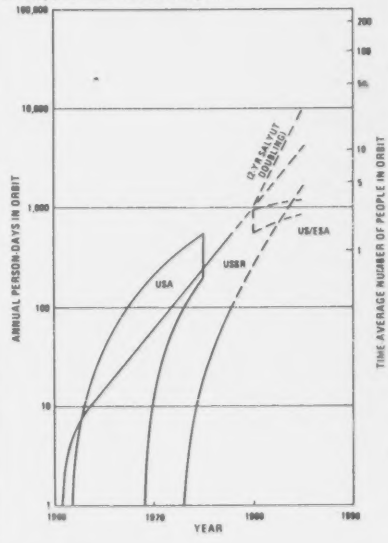
F-1A CUMULATIVE TIME OF MAN IN ORBIT



F-1B ORBITAL POPULATION GROWTH
Envelopes enclose the scattered points.



governmental and commercial, now exist. As of September 1977, 146 nations reported space-related activities, 126 non-launcher nations had 354 international space memberships, 35 had cooperative space programs, and 21 had 78 bilateral programs.[5] As of 1980, seven powers will own orbital launch systems and 21 will have satellites.

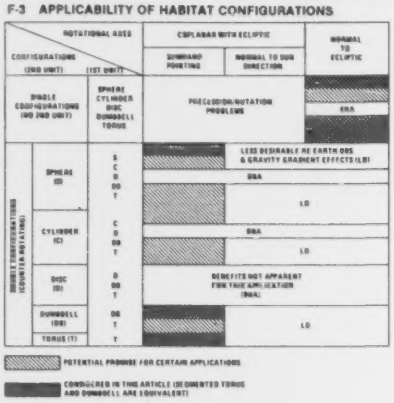
Many times astronautical concepts and commitments have crossed oceans and borders. After coming to the U.S., Wernher von Braun with members of his German team and leaders of the American scientific community jointly formulated in 1952 a forward-looking space program which included a permanent Earth-orbital station (F-2).[6] Serving as a platform for scientific observations of Earth and the cosmos, von Braun's station would rotate at 2.7 rpm to produce 0.35 *g*. It would provide submarine-like living accommodations for about 80 people. This concept remains technically feasible except that the Van Allen radiation belts subsequently discovered require an orbital altitude less than about 600 km, and the station would need a shielded "storm cellar" to protect permanent inhabitants against radiations from occasional solar flares.

Since von Braun's proposal, many concepts for permanent orbital stations have been studied quantitatively by government and industry, most of them modularized assemblies designed for no more than a few tens of people. But on a qualitative basis, Romick in 1956 suggested the concept of an Earth-orbital "city" of 20,000 inhabitants with a rotating residential disc at one end, constructed around a core formed of used rocket fuselages.[7] Also qualitatively, in 1967 Ehricke proposed an Earth-orbital "resort hotel" for 1200 people incorporating large zero- and partial-gravity "dynariums" for recreation and sports.[8] In 1974, jumping to a more ambitious scale, O'Neill proposed "colonies" constructed at lunar distances from lunar materials, and accommodating 10,000 to several hundred thousand people, an idea which has now received considerable study.[9-15] In support of O'Neill's work, Driggers explored a 2000-person "construction shack" at lunar distance.[10]

Despite this stimulating work, near-Earth habitats in the size range of, say, 50 to 10,000 people, have received little systematic quantitative study. (I have suggested a near-Earth "protocolony and technology station" for several hundred people, and a related design point for a 1000-person prototype colony has been explored in some detail.[16,15]) For reasons developed in this article, I believe that an international orbital research habitat should be somewhere in this size range; and the

F-2 Von Braun proposed a permanent toroidal Earth-orbital space station in 1952. Eighty persons would live in the 76-m-diam station in synchronous orbit at 1730-km altitude. Illustration by Chesley Bonestell in *Colliers*.[5]

F-3 APPLICABILITY OF HABITAT CONFIGURATIONS



T-1 HABITATS CONSIDERED
Torus segmented at smallest population to maintain minor radius at no less than 2.5 m.

CONFIGURATIONS / PARAMETERS		TORUS						SPHERE					
		SINGLE			DOUBLE			SINGLE			DOUBLE		
		RIM	TOTAL		RIM	TOTAL							
POPULATION		10	25	50	25	50	100	50	150	500	100	300	1,000
ILLUMINATION		ELECTRICAL						DAYLIGHT					
ROTATION	AXES	NORMAL TO ECLIPTIC			SUNWARD			NORMAL TO ECLIPTIC			SUNWARD		
	PSEUDOGRAVITY, g (MAX AT 3 RPM)	0.5	0.9	1.0	0.5	0.9	1.0	0.25	0.5	1.0	0.25	0.5	1.0
	RADIUS, m	47.5/2.5		95/5	47.5/2.5		95/5	25	50	100	25	50	100

article explores what such a habitat might be like, how long it might take to construct, and how much it might cost.

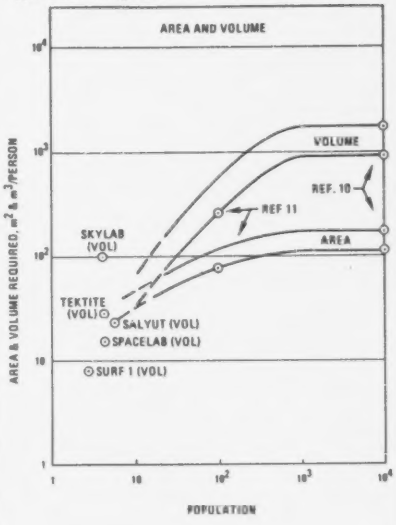
Each habitat would include the means for Earth observation (resources, environment, weather, etc.), cosmological research, materials and products research (including pharmaceutical, biomedical, agricultural and ecological studies), and basic technology development for advanced space systems, including information handling, large structures, and energy systems.

Habitat design assumed the following characteristics: population, 10 to 1000; construction, integral and done in orbit (aluminum shell with 218.7 MPa tensile strength); orbit, Sun-synchronous at 550-km altitude (est. ΔV required for orbit maintenance, 20 m/sec/yr); photovoltaic power (fuel cells for eclipse/reserve); no extensive or complex windows.

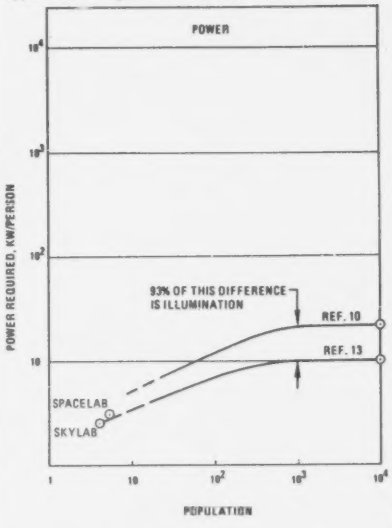
Internal environments include pseudogravity at 3-rpm max (Coriolis limit), 0.5 atmosphere (50% O_2, 50% N_2), radiation protection by solar-flare shelter providing 5 t/m^2 protection (adequate against the largest recorded solar flare, of Feb 23, 1956), area and power adequate for partly to fully closed ecoculture depending on habitat size, and soil 0.3 m deep over about 40% of habitable area.

Programming and scheduling are based on a "surprise-free" environment with no extraordinary drivers, and operational logistics are based on the conservative assumption of an open ecosystem with partial oxygen recovery.

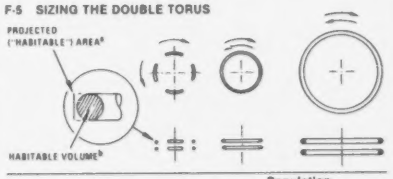
F-4A HABITAT SIZE PER PERSON
Upper curves with agriculture. Lower curves without.



F-4B HABITAT POWER PER PERSON
Upper curve with agriculture. Lower curve without.

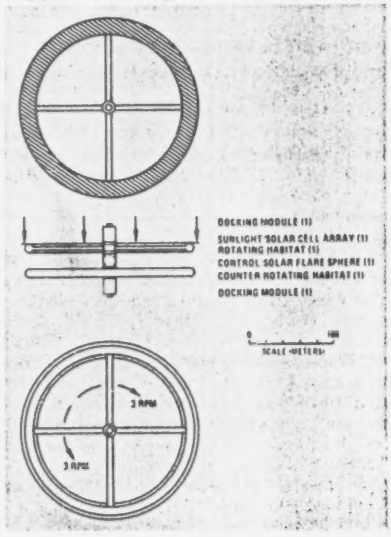


F-5 SIZING THE DOUBLE TORUS



Characteristic	Population 20	50	100
Torus radii, m	47.5/2.5	47.5/2.5	95/5
Pseudogravity, *g*	≤0.5	≤0.5	≤1.0
Habitable area, m^2/person			
Required from F-4	37	61	110
Available	38	62	123
Habitable volume, m^3/person			
Required from F-4	78	198	580
Available	146	234	938

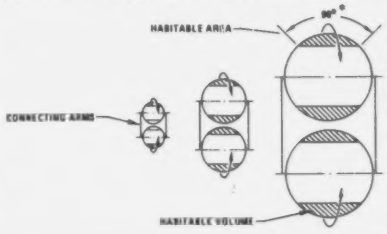
F-6 DOUBLE TORUS HABITAT
For population of 100, ≤ 1.0*g*, rotation axis pointing Sunward.



The habitat directly serves research and technology studies only, and not large space operations such as information-handling platforms, solar-power satellites, materials processing factories, or military activities. Only in this way can such an international cooperative enterprise be as free as possible from political, economic, and military obstacles.

F-3 presents a matrix of possible habitat configurations. T-1 and F-3 describe toroids and

F-7 SIZING OF DOUBLE SPHERE
Ninety deg selected as balance between use of space livability plus reasonable *g* range. At 90° minimum *g* is 0.7 maximum *g*.



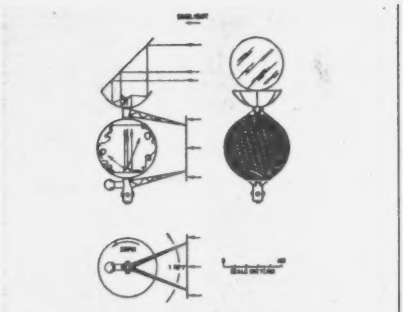
Characteristic	Population 100	300	1000
Sphere radius, m	25	50	100
Pseudogravity, *g*	≤0.25	≤0.5	≤1.0
Habitable area, m^2 /person			
Required from F-4	110	145	172
Available	111	148	178
Habitable volume, m^3/person			
Required from F-4	580	1196	1800
Available	463	1236	2966

spheres selected for consideration. F-4 gives habitat area, volume, and power requirements. The curves in F-4 are plotted from case-by-case analyses in which requirements were broken down into "urban" and "agricultural" elements (as in Ref. 12, 13, and 15) plus a "research" element. Eclipse and reserve power requirements were set to permit uninterrupted research at full power should photovoltaic power be lost.

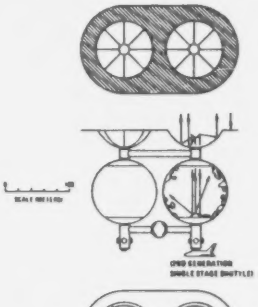
Sizing and design for toroidal configurations are shown in F-5 and F-6, and for spherical configurations in F-7, F-8 and F-9. F-10 gives habitat mass trends as a function of population. The curves in F-10 are plotted from individual mass estimates aggregated from a 22-item mass breakdown for each of the twelve point designs considered. The mass estimates are based on relationships and assumptions extracted from Ref. 10-15.

T-2 presents a possible evolutionary sequence of Earth-to-orbit transportation concepts and their costs. Data from T-2 and F-10 are combined in F-11 to show which vehicle concepts provide lowest transportation cost as a function of habitat population. A growth version of the Space Shuttle would suit populations between about 15 and 150 people. Between 150 and 750 people requires a second-generation "priority" Shuttle. Above 750 people calls for a second-generation "heavy" Shuttle.

For three toroidal and three spherical point designs, habitat program costs were estimated year by year according to a 16-item breakdown, and



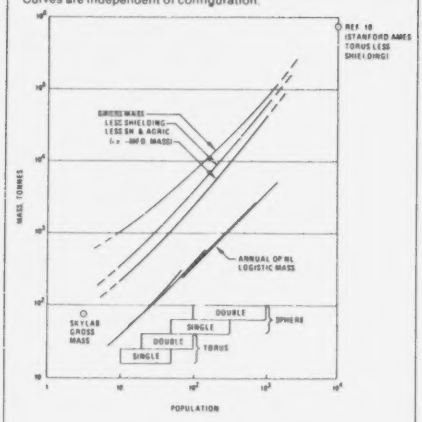
F-8 Single-sphere habitat would house 150 people at 0.5 *g* or less. Solar array would cover the large disc at right. Nonrotating cylinder at bottom would have zero-*g* labs and docking and entry module. Small sphere at bottom would serve as control room and shelter during solar flares.



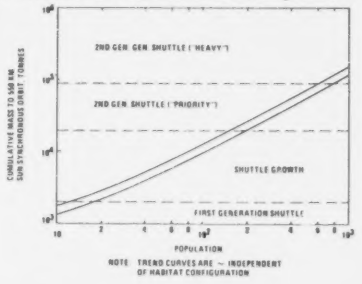
F-9 Counter rotating double sphere habitat would house 300 persons at 0.5 *g* or less. Solar array would cover shaded area.

ROBERT SALKELD (AF), consults to industrial and government organizations in aerospace and military planning, has held management positions at System Development Corp., United Aircraft, the Aerospace Corp., and Space Technology Laboratories, and took part in early studies of reusable launch vehicles and spacecraft, space stations and advanced strategic concepts. As a consultant he originated the mixed-mode propulsion concept for reusable single-stage shuttles and tugs. At STL, he worked on the Pioneer I deep-space probe. His book, *War and Space* (Prentice-Hall, 1970), examines military and political aspects of space.

F-10 HABITAT MASS
Curves are independent of configuration.



F-11 EARTH-TO-ORBIT TRANSPORTATION OPTIONS
Upper curve shows mass for 20 years of operations, lower curve, for 10 years. Both are independent of habitat configuration.


2ND GEN. GEN. SHUTTLE ("HEAVY")
2ND GEN. SHUTTLE ("PRIORITY")
SHUTTLE GROWTH
FIRST GENERATION SHUTTLE
CUMULATIVE MASS TO 560 KM SUN SYNCHRONOUS ORBIT, TONNES
POPULATION
NOTE: TREND CURVES ARE ~ INDEPENDENT OF HABITAT CONFIGURATION

T-2 POSSIBLE EVOLUTION OF EARTH-TO-ORBIT TRANSPORTATION VEHICLES

VEHICLE	PAYLOAD[a] MASS(t)	PASSENGERS	COST $10^6 DDT&E	$10^6/tn	$10^6/t
FIRST GENERATION SHUTTLE	17 (+)	10	n.a	22.0	1.30
FIRST GENERATION SHUTTLE GROWTH[b]	34 (or)	80	2.2	10.5	0.22
FIRST GENERATION SHUTTLE DERIVED HEAVY LIFT[b]	95	n.a	3.3	10.4	0.10
SECOND GENERATION SHUTTLE ("PRIORITY")[c]	19 (or)	00	5.2	1.2	0.063
SECOND GENERATION SHUTTLE ("HEAVY")[d]	82 (or)	220	7.0	3.6	0.044

[a] PAYLOAD TO 560km SUN SYNCHRONOUS ORBIT
[b] REF. 16 [c] REF. 17 [d] REF. 18

collected into six major cost categories. Those six were then profiled as a function of time (F-12). Habitat cost estimates were based mainly on historical and projected cost data for large NASA programs and only partly on other costing schemes,[10,15] which I think to be generally over-optimistic. (T-2 shows the basis for transportation costs.)

Total costs, including ten years of operations, range from $6.8 billion for a 10-person habitat to $46.2 billion for a 1000-person facility. Peak-year funding varies from $1.5 billion for 10 people to $4.5 billion for 1000 people.

Development and construction time ranges from eight years for 10 people to 17 for 1000 people. Construction times assume assembly productivity of 450 t/man-year (three-shift basis).[12] The 300-person double-sphere habitat and a construction time of five years requires a construction crew of 10 persons supported in a modest space station (included in the "theoretical first unit" costs).

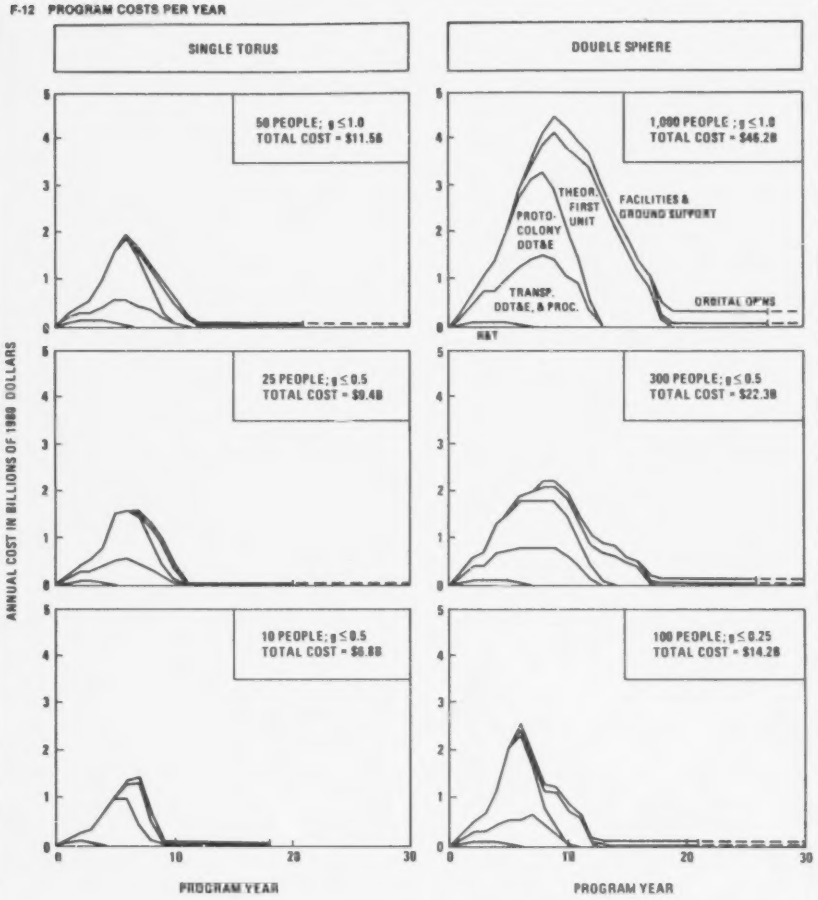
These cost trends are summarized in F-13 together with program cost per person, assuming each person occupies the habitat for a six-month period. Thus, for a 300-person colony over a ten-year period, 6000 of the world's researchers and their families could conduct studies in and about the orbital habitat at a per capita cost of $3.7 million. As indices of economic preferability, F-3 shows products of the curves for program cost, cost per person, and peak-year funding. The resulting "bucket curves" suggest that the cost-optimum population of an Earth-orbital research habitat may be between 200 and 500 people.

Design, development, construction, and operation of such a habitat present challenges in many fields of engineering and biology, including fabrication techniques, ecosystem and thermal control, power and illumination distribution, health and medical management, maintenance, repair, safety and emergency operations. After serious scrutiny by the technical community in recent years,[7-18] it appears that essentially all of these challenges can be mastered with currently understood technology. Salyut, Shuttle, Spacelab and their growth versions will provide the basic knowhow to undertake development of permanent orbital habitats.

Decision to pursue such a project would be bold indeed. As with any forward-looking enterprise, there are many arguments for caution and rejection—cost, risk, time, fears of "technology giveaway," and so on. Politically, it might develop that the only practical way to undertake the program would be on a national rather than international basis.

But the spirit in which such a large and important step is taken will shape the course of space de-

F-12 PROGRAM COSTS PER YEAR



velopments. We accept that many phases of space activity will be competitive politically, economically, and militarily. I believe that those aspects should be balanced by a major undertaking on a truly cooperative basis, that the nations should move toward permanent space occupancy and human migration into space as a common effort of, by, and for the whole world.

Acknowledgement

For kind help in checking the historical aspects of this article, I would like to thank Frederick C. Durant III of the Smithsonian Institution's National Air and Space Museum.

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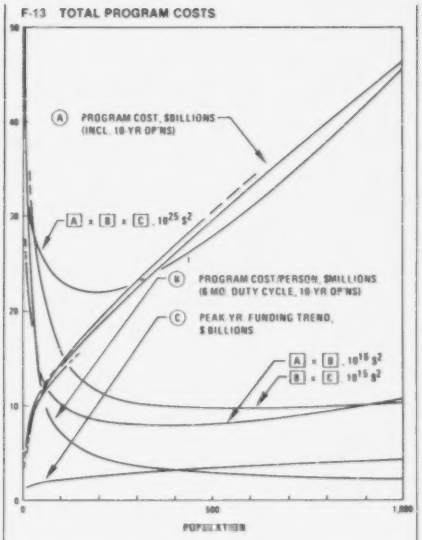
F-13 TOTAL PROGRAM COSTS



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INTERNATIONAL REACTION

Astronautics & Aeronautics *solicited the responses of space figures around the world to Salkeld's view of an occupied space platform by 1990 as the next major milestone in the conquest of space and an inspiration for international cooperation. Of the four who replied—from Japan, Europe, and the U.S.—three back a large space station. Gerard O'Neill would rather head in a different direction. George Low's comments should correct the mistaken impression* A/A *gave in its April issue that he advocates an early manned mission to Mars. A quote lifted out of context appeared on page 11.*

USE OF NONTERRESTRIAL MATERIALS A BETTER GOAL

The notion that an international low-orbital space station, a kind of upgraded Apollo-Soyuz, could become a high-priority project merits discussion. It seems, though, quite far from the mainstream of interest in advanced space programs—automated observation and communications satellites, development of large extended space structures, and the controversial satellite power station. The use of nonterrestrial materials for producing structures in space, although only in the study and planning phase and itself controversial, certainly has far higher possible impact on future programs than an international space station shorn of the research activities that have highest potential for future growth.

Very few researchers are working on space-station or space-habitat design at this time, so it is good that Salkeld is contributing effort to it. I have some reservations about his conclusions. *Space-Based Manufacturing from Nonterrestrial Materials* (*Ed.*—Edited by O'Neill.),

Vol. 57 in AIAA's Progress Series, is the only reviewed material published so far bearing on space-habitat design. It is well worth studying but does not appear on Salkeld's reference list.

The most detailed studies so far indicate that the lowest-cost form of 1-*g* space station would be two or more surplus Shuttle external tanks tethered together by long steel cables. Rotation would give them a pseudogravity along the tank axes, and would allow decoupling entirely the area and volume of the station/habitat from its gravity and rotation speed. Salkeld's designs lack that decoupling, and are rather inefficient in consequence. For space habitats fabricated rather than converted, the "Crystal Palace" is the strongest and best shielded for its mass. Spheres at 1 *g* become rather efficient and attractive above 100-m radius if the volumes near their 0-*g* axes are used efficiently, and if natural interior sunlight is taken as an important positive quality. Below 100-m radius the rotation rates required for 1 *g* would disorient some people. Toroidal designs that seemed reasonable in the 1950s hold less attraction now that we know how much shielding a habitat in orbit must have.

The first months of 1979 have seen considerable achievement in advanced space programs, but also a severe threat. Excellent studies by Convair and MIT have confirmed the economic utility of using lunar materials even from a very early stage in any large-scale program of space construction. Those studies concluded that 90-96% of the mass, of, for example, a power satellite could be obtained from common lunar elements. The Lunar and Planetary Institute of Houston has concluded in another fine NASA-supported study that a space-based plant using lunar materials could process 50-100 times its own mass in a year. Complementing these studies and in cooperation with them, a series of workshops coordinated by Princeton has explored scenarios of minimal scale, cost, and innovation aimed at achieving as soon as possible the productive use of nonterrestrial materials.

Though it is too early to state final conclusions, I believe the evidence so far presented shows that the first productive use of nonterrestrial materials could be obtained for a capital cost lower than that of Shuttle development for producing a few thousand tons per year of finished products. That direction of research particularly excites me because of its practicality and immediacy. Later, 100,000 tons—90% of an SPS—per year from lunar materials could be reached without a rocket vehicle beyond the Shuttle. The one development crucial to it appears to be learning how to process lunar soil chemically. A small-scale bench-chemistry effort to establish that technology seems to be to be of the very highest priority.

Unfortunately, in the continuing reorganization that has occupied much of the time and effort of NASA during the past two years, the program office that funded these innovative studies vanished early in 1979. With it went the modest but highly productive study program on using nonterrestrial materials, a program that in 1978 absorbed about 10^{-4} of the NASA budget or 10^{-6} of the federal budget.

Forces within the government interact complexly at this time. Senator Harrison Williams's High Frontier Feasibility Act signed into law in 1978 requires a study by the National Science Foundation of "the feasibility of transmitting solar energy to Earth by using orbital structures manufactured from lunar or asteroidal materials." That study is just now being organized. The Department of Energy's investigation of satellite power has concentrated, quite wisely, on environmental questions, and to the surprise of many has so far discovered no unacceptable effects. DOE recognizes the need to broaden its study and to consider a wider range of routes to satellite power. Congress continues its pressure for a stronger space program, and in part because of concerns over a possible arms race in space, keeps on funding the Shuttle overrun. That is important. The Shuttle is the only really new vehicle—not counting vehicles that would use existing engines—that a program for using nonterrestrial materials would need.

Gerard K. O'Neill

FITS JAPAN'S SPACE POLICY

I am a Commissioner of Space Activities on the Commission of Japan, which is responsible for making the space policy of the Japanese government. This commission issued the "Outline of Japan's Space Development Policy" in March of last year. In this development, we emphasized the importance of international cooperation as one of the three basic principles of our space development policy. Japan is now developing various kinds of scientific and application satellites and launch vehicles for its own space programs. Also Japan plans to use the Space Shuttle for scientific observations and space processing experiments. The document says, "With the technological resources gained from these activities, Japan will play a suitable role by participating actively in such programs as the second phase of the Space Shuttle and a large-scale space station for the sake of efficient space development of the world."

I have read Salkelds' article with great interest. I personally feel very strongly that his idea will just fit our space policy. I hope his article will draw the attention of many people of various countries so that his idea will be supported by the international space community. I am sure Japan would join a preliminary study group of the international community from the beginning, if it were set up.

Shigebumi Saito

CENTRAL TO LEADERSHIP IN SPACE

I propose that the United States establish a national purpose, as follows: "It shall be the policy of the United States to regain a position of world leadership through strength in technology; to use technology development as a significant force in world politics; and to recognize dependence on technology as a major contributor to a healthy economy."

Clear goals, objectives, specific programs, and timetables must follow such a first step. As one of those goals I suggest leadership in space.

Why leadership in space? Here are some reasons:

- The exploration of space appeals to the human drive for adventure and the human thirst for knowledge. It inspires our younger generations, and evokes the spirit of all people of all ages. It provides the spark for optimism about the future.
- The use of space has become indispensable in today's world. Communications and weather satellites provide essential services. Environmental and resources satellites are beginning to furnish accurate reports on global Earth and ocean resources and conditions. Accurate agricultural forecasts lie just around the corner.
- Space technology sets the pace for other technological developments. Our economy is driven by productivity. Productivity is tied directly to technological advances.

And space technology is at the cutting edge of all technology.

• Space projects offer opportunities for international policy initiatives. Options exist for cooperation or for competition with advanced or developing nations.

• Space projects demand an advanced and innovative aerospace industry—an industry essential to our national defense. In time of peace, space projects can help maintain the readiness of that industry by involving it in productive civilian efforts.

Many opportunities exist for leadership in space. The constraints today are largely economic and not technical. The potential for returns, when measured in terms of a national purpose, is great. We will soon be in a unique position to undertake a major new initiative in space by making use of the essentially unlimited access that the Space Shuttle will offer. But the Shuttle alone is only a tool—a key that will open the doors to other opportunities.

A program for space leadership should result in new services from space, and an exciting program of space exploration. There is no alternative as a central element of the program to a permanent manned orbital platform leading to continuous human beneficial occupancy of space.

A leadership program, by definition, involves men and women in space. We all know that we are kidding ourselves if we say anything other than that.

In manned space exploration, the next logical step is a flight to Mars. Such a program is beyond our current means. Scientific exploration will, for the time being, be carried out with unmanned vehicles except for observations made from Earth orbit.

A space platform fulfills many purposes. It can serve as a core for experimental laboratories and an outpost for managing scientific observations and services from space. In can assist commercial enterprises, be a construction base for assembling very large orbital structures needed for information and communications systems, and for collecting solar energy for use in space, or at least experimentally, for use on Earth.

A program of space leadership would deliver economic and inspirational benefits for the United States, and the world.

George M. Low

Taken from remarks made at a session of AIAA's February Annual Meeting.

SOONER OR LATER

Only an extremely brave—or equally foolish—man would attempt to dogmatise on the space achievements of the next decade. The past two decades have seen the transformation of writers' dreams into reality, and there is no reason to doubt that either man's imagination or his technical prowess has diminished. On the contrary, as Salkeld shows in his article, the ideas keep bubbling up, and the technological achievements are still managing to keep pace. The limiting factor during the next decade is likely to be the growing insistence of governments to invest money in space programs only in relation to their foreseeable utility. This trend will certainly continue throughout the coming decade and a reversion to the large prestige projects of the recent past is unlikely. Thus, space managers must try to invest available funds in such a way as to respect the wishes of their masters and at the same time make some modest progress toward the programs which sooner or later must come: large constructions and habitation in space.

I, too, am hopeful that this next great step forward will encourage international cooperation, but this will not come of its own accord. It will require constant vigilance and tolerance, but the opportunity is too precious to miss. **Roy Gibson**

FRESH VIEW FOR PRC

Since the first successful launchings, people have not only made artificial Earth satellites to be beneficial to mankind—for instance, they have not only developed communication, navigation, Earth-resource and meteorology satellites, but also created a lot of new scientific research fields which have become new subjects, such as space astronomy, space geology, and space chemistry—as a result of the development of space technology. Also mankind has made some valuable achievements in near-Earth, Sun-Earth, and outer-planet explorations. The development of space science and technology clearly has broad prospects.

I cannot comment in any official way on the plausibility of Robert Salkeld's article on living in space, but I enjoyed reading it and have not previously seen such detailed conceptions for Earth-orbital research habitats. **Chen Jie**

Secretary General
Chinese Society of Astronautics

Gerard K. O'Neill, professor of physics at Princeton Univ., chairs the Task Group on Large Space Structures of the Universities Space Research Association.

Shigeburni Saito, professor at the Univ. of Tokyo, serves on Japan's Space Activities Commission, and as a VP of the IAF.

George M. Low, president of Rennselaer Polytechnic Institute, served as deputy administrator of NASA from 1969 to 1976.

Roy Gibson, director-general of the European Space Agency, this year also serves as president of the International Astronautical Federation (IAF).

THE EXTRATERRESTRIAL IMPERATIVE

Dr. Krafft A. Ehricke

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holder.

FAR FROM being isolated in space, Earth is a spaceship with external supplies. The most fundamental commodity, energy, comes from an external source. Terrestrial environment and the biosphere run on the 1.5 billion billion kilowatt-hours of solar energy intercepted annually.

Earth and space are indivisible. Only a few centuries ago did man begin to understand this indivisibility in terms of natural laws. Now we experience it by going into space and returning at will and by conversing with our automated scouts all over the solar system. In a few years this indivisibility will express itself in the productive industrial use of extraterrestrial environments.

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There was a time when man was slow to accept the mounting evidence that Earth is not flat. Today it is necessary to understand that we do not live in a limited, isolated, closed world. Our world is open to the cosmos and contains all the future and growth potential the human mind can envision. But ours is not, and probably never will be, a problem-free world.

Humanity faces the most complex task of its history so far. Stated in a solution-oriented way, it is necessary gradually to reorganize this planet at two levels. One must deal with the competing necessities of biosphere and mankind with all their environmental and climatic consequences. On the other level, it is necessary to resolve the demands of competing nations and worlds within mankind's hierarchy of socioeconomic developmental levels and the "Christmas tree" of sociopolitical, ideological, and military consequences.

The way to solve a problem is to forge concepts that permit one to look beyond the problem. Even today's conflicts between humankind and the environment, so seemingly insolvable to catastrophists and antitechnologists, can be turned from conflict to juxtaposition of interests in the crucible of higher concepts. Such a concept is the realization that we can enhance the "supplies" to spaceship Earth, beyond energy, to include materials and information acquisition/transfer for the mainstream of human civilization.

We have not yet exhausted outright any needed resource. There are vast land areas, such as the Sudan and others, that could feed all mankind once developed. Minerals and energy abound on Earth and beyond if we have the resolve to develop them rather than retreat into stagnating stupor that would hurt our environment more than the advance of a benign industrial revolution taking into account terrestrial and extraterrestrial environments. Technology will not be the cause of our demise, but lack of willingness to advance it beyond the early, transitional state may be. Technology is the source of our options.Options are the basis of a future that keeps us above the level of pawns. Those who condemn technology, properly applied, eliminate our options. They commit the worst of all pollutions—the pollution of our future.

To find the approaches to solutions that can properly safeguard the future of our civilization with its unparalleled contributions to the human factor of life, we need a better understanding of what we face. We need insight into the long past that shaped us and set our course—back to life's silent and successful struggle for survival and growth on a primordial planet.

The Extraterrestrial Imperative is a manifestation of larger evolutionary cycles—an integral part of life's commitment to expansion and growth. The reality of the biosphere testifies to this fact. This splendid system assures our planet's unique position as a colony of life for the duration of our star, unless the climatic or genetic foundations are destroyed. When the planet's accessible (organic but abiotic) energy sources became exhausted some three billion years ago, life's response was a vigorous struggle for survival through growth. Certain organisms developed the enzymes needed to utilize solar energy. This shift to an extraterrestrial source was the first great industrial revolution on our planet. Driven by solar energy, the evolving chlorophyll molecule became the technical instrument by which to turn primordial energy and matter into chemical energy in biotic organic compounds. Mass production of the basic staples of life was initiated. The by-product, free oxygen, began to pollute the chemically nonaggressive environment of Earth and became a self-induced growth driver by which life stimulated itself into a giant evolutionary advance—a global biosphere—catapulting intelligent life into existence.

The point is that technology is as old as life. Technological advances and enlargement of the resource base beyond the limits of this planet became the bridge for survival and

growth. A system evolved, so stable that it could tolerate the ascent of a new, intelligent life form able, in turn, to interact with primordial matter through its own technology. This is the basis for the new thrust of the Extraterrestrial Imperative. For small planets, such as Earth, the extraplanetary imperative is a necessity to ensure long-term survival. In return, this imperative offers a higher, virtually unlimited, evolutionary ceiling than appears available to much larger, exclusively planetogenic bioworlds as might have arisen on Jupiter.

The fact that neither technology nor reaching beyond Earth is exactly new, but natural growth options exercised before, puts the human reality of our time into perspective. The reality has two anchor points: (1) That the chlorophyll molecule and the human brain are the only true superpowers on this planet. They must find a way to coexist, and, not being intrinsically incompatible, they can. (2) That humanity does not live as a mankind but is "organized" as an aggregate of some 140 nations. Most of these nations strive to improve their standard of life or safeguard social standards achieved and extend them to the less advantaged. Without the means to grow—and, like it or not, these means include material resources and the ability to process them—general stagnation will create a shrinking-water-droplet world in which competition for growth turns into a grim struggle for survival.

In an industrial civilization, all nations tend to profit from technoscientific advances made by some. In a shrinking-water-droplet world, this humane symbiosis cannot last. When it breaks down, it will pull all into a maelstrom of regression, burdening both the biosphere and the hard-won standards of our civilization—possibly to the breaking point.

Space industrialization as a phenomenon of human development presents the systematic breakthrough into a new Open World at a time when many formerly open world characteristics on Earth (resource abundance, waste sink capacity) fade, and the terrestrial environment begins to assume the appearance of a closed world in relation to human activities. This has two important consequences: To man, the cause of the devolves the burden of preserving the terrestrial environment. Without projecting his productive capabilities beyond the terrestrial environment, man will not be able to carry the burden in the long run without severely stunting the human growth potential.

We cross into the new Open World through a multitude of environmental frontiers—subatomic, atomic, molecular, the cosmos of the human mind, and the cosmos of the universe. In pragmatic terms, in the Open World new environments are what it is all about; they are the source of all national wealth, the basis for all new options. Through their exploration and productive use (industrialization) both the spiritual and the material causes of mankind are advanced.

This concept permits us to see beyond what seems to be an irreconcilable confrontation of man and environment, unless humankind backs down into a no-growth mode. Our technology supports both of our main strategic options—a benign industrial revolution on Earth and an extension of our industrial capabilities beyond Earth. We can see more clearly that we are not stonewalled; we have choices. Therewith the buck stops again right here, with us. It leaves us a choice between two ways of life of either organizing scarcity or creating wealth.

Organizing scarcity reveals the resolve of a viable society to meet and overcome a state of need. The emphasis is on overcoming, because a healthy society will reject the notion of managing scarcity (not to be confused with prudence) as a way of life. Creating wealth is the natural state of life, and mature men and women understand that this is not synonymous with ever increasing consumptive affluence but is equally the basis

for safeguarding and developing human values. Current criticisms of industrial lifestyles, which in fashionable zeal tend to exceed the bounds of justifiable cause, should not blind us to the fact that success in creating wealth underwrites a degree of human freedom and a level of social services unmatched by any other lifestyle or civilization, past or present. The quality of these industrial lifestyles sparks the incentives and sets the goals in many developing societies equally determined to set their own shade of life within industrialization. Greater productivity leaves more time to services and human development. Industrial progress without increased burden on the human environment prevents increases in productivity from becoming self-defeating.

The three initial space industrial product areas are information, materials, and energy. Once set up properly, space industrial systems in each of these areas are exceedingly productive. This has clearly been demonstrated by satellites for information transmission and sensory information acquisition. It is equally true for the energy and the material processing sectors. Through the development of space-related industries in the sectors of electronic (information-related) services, products, and energy, new jobs are created. The industrial resource base is broadened. The economies of industrialized and industrializing countries are strengthened. Public health and social services will benefit. The industrial use of space in the information services sector is already a reality, although the potential is far from exhausted. Beyond 1980 the Space Shuttle-based Space Transportation System (STS) will form the economic basis for broadening the commercial applications in the information sector as well as for developing the energy and product sectors.

Information transmission satellites have made great progress in the past decade in global communications, from Intelsat I (1965), with a capacity for 240 telephone circuits, a design lifetime of 1.5 years, and an investment cost $32,500 per circuit-year, to Intelsat IV-A (1975), with 6000 circuits, a lifetime of 7 years, and $1100 per circuit-year. Between 1965 and 1972, the typical Intelsat user fee per circuit-year had dropped from $32,000 to $9375. In 1979, Intelsat V (with ten years lifetime) will come on line, doubling the number of circuits at a possible cost reduction to $500 per circuit-year. Of growing importance is the field of domestic communications satellites, using channels leased from Intelsat spacecraft (as have Algeria and Norway) or dedicated satellites (U.S., Canada, Indonesia). Data exchange satellites, designed for the transfer of wideband, high-rate data blocks rather than voice or TV circuits, are under development for the business market in the U. S. and Japan. These will be the first to use rooftop terminals.

The increase in satellite antenna size, channel numbers, and radiated power, made possible by the STS, will accelerate the trend

toward increasingly smaller Earth terminals. Direct-broadcast satellite systems and communication satellites to mobile terminals down to personal communication via handheld or wristwatch tranceivers will then become realities in the 1980–90 decade. The latter group, in particular, has no competition from hardware links on Earth and only marginal competition from high-frequency radio. A first step in this field has already been taken. Marisat, stationed over the Pacific, Indian, and Atlantic Oceans, provides shipboard and mobile offshore telephone circuits.

Behind these technological advances lies a momentous contribution to modern society. In the nineteenth century, economic growth rested on mass transfer, the transfer of goods from one location to another. In the first half of the twentieth century, the economic foundations shifted to the transfer of energy. Now, as society is based increasingly on services, information transfer will continue to rise in importance well into the twenty-first century. Beginning in the 1980s, growing numbers of people will telecommute rather than commute to work. If, by 2000, the expected mileage traveled in this country is reduced by 18 percent, the annual fuel savings correspond to some 700 million barrels of oil (at an average of 27 mi/gal) and at least $28 billion (at 60¢/gal and 5¢/mi).

There are more than 200,000 doctors' offices in this country today (general practitioners, specialists, and federal offices). Interconnection by office-to-office communication links permits such advances as ready consultation with specialists anywhere, instant updating on diseases, treatments, and medications, and expanded use of paramedics in mobile units. Eventually a global medisat system will make "home type" medical services available in the remotest areas, based on signals or even pictures defining the patient's state to supervising doctors. In developing countries, public health services can be improved much faster and at a far lower investment than could be hoped for without satellites.

Similarly expanded opportunities are provided in education, including special services to the handicapped and televised instructional courses for general education. To increase adult living competence is a much-needed service in our fast-changing time. Televised instructional courses with massive "enrollments" of tens to hundreds of thousands would reduce cost from hundreds to a few dollars per participant. Public order and safety, electronic mail directly to our homes, teletraveling, teleshopping, new ways of contacts between peoples all over the world, the expanded opportunities to tune into major scientific and cultural events anywhere in the world—including, eventually, activities in orbit, on the Moon and beyond—are other promises of the emerging era of space-based information transmission.

But the explosive growth in the capacity to transmit information also means an equal growth in the capacity to transmit misinformation. The potential for manipulating people's minds will increase accordingly. Again, the buck stops on the human desk, since technology itself is neutral. However, these dangers are a blessing in disguise. How else can we improve unless we face the dangers we pose to ourselves? It is the way of nature to immunize through infection, not to protect by creating a sterile environment.

The other branch of information services, namely, sensory information acquisition, is rapidly becoming integrated into the mainstream of economic and environmental activities worldwide. The well-known services from weather forecasting to crop measurement already are worth billions of dollars in agriculture and forestry, pollution control and public health, tourism and leisure time industries. As population, industrialization, and urbanization increase, reliance on

information acquisition from space for the management of food, water, and land and ocean resources will become indispensable. Our sensitivity to climatic variations will grow. Therefore, beyond weather forecasting lies the challenge of understanding the mechanisms and dynamics of regional and global climatic variations. NASA's plans for a large, eventually manned, Solar-Terrestrial Observatory in the late 1980s are of crucial importance. Certainly, by the turn of the millenium, the ability to assess man's impact on climatic changes and the ability to forecast regional or global climatic variations will have become critical to the survival of civilization.

To educate without offering prospects for utilizing the improved human resources through meaningful employment can have destabilizing social effects. In industrialized countries, and even more so in developing countries, education must go hand in hand with economic growth to ensure adequate job markets in the production and services sectors. Here the key is energy.

Our present energy world is shrinking rapidly as continued global industrialization demands its expansion. To reverse this process, the development of coal, fission, solar, and fusion sources must be pursued. The age of cheap, abundant energy need not be over; but it is not only vital to our time, it is the most important heritage we can bestow on succeeding generations to ensure their quality of life on a planet from which we skimmed the richest and most readily accessible resources. In the energy sector, more than in any other, the future depends on *our* problem-solving capacity, for, as our bodies cannot exist long without breathing, our industrial civilization cannot last through a prolonged period of lack of available energy. Therefore, we cannot leave this problem to posterity. Our problem-solving capacity, in turn, is enhanced by adding a new industrial option bank in space.

In the space energy sector, one must distinguish between using energy in space for material processing and production, in order to reduce energy consumption within the biosphere, and utilizing space as a source of energy for use on Earth.

Photovoltaic systems are a natural for supplying energy to orbiting information and manufacturing systems. Here, NASA-planned power units from 50 to perhaps 1000 kwe size will be adequate, at least for the 1980s. For example, a very advanced person-to-person comsat with 1.2 million channels requires about 600 kwe.

Most anticipated space manufacturing processes indicate power requirements within 500 kwe. Due to the strength of the gravitational pull of Earth and the associated transportation costs, only items of relatively low mass but high quality and product value are economically competitive. In the lunar-industrial product sector, on the other hand, larger masses and cost-effective extraction of desired elements from lunar minerals and oxides are the key to economic viability. Here much higher power levels are involved. Unavailability of solar energy during lunar night and the desirability of underground extraction render fusion power particularly attractive.

Controlled fusion power is the key to the ultimate economy and versatility of space industrial productivity. Consequently, plasma research and experiments toward fusion reactors should be given high priority early in space industrial research and development planning. Fusion reactors are complex, with complex auxiliary systems for plasma heating and fueling, complicated blanket and shield structures, energy storage and tritium recovery, and handling. Nevertheless, it appears that operation in space can reduce many of the most difficult engineering problems. A magnetically confined fusion plasma requires a surrounding vacuum of 10^{-6} torr (1.3 billionth of an atmosphere). At lesser vacuum, the plasma pressure becomes impractically high. Space offers a vacuum of 10^{-9} torr or less, greatly

reducing plasma and required pressures.

Terrestrial vacuum chambers are relatively small because of the difficulties and cost of maintaining such high vacuum on the ground. Since 80 percent of the energy released by a deuterium-tritium reaction resides in neutrons that cannot be confined magnetically, the inner chamber walls are exposed to savage neutron flux densities, creating an environment that is comparable only to that close to a detonating hydrogen bomb. The resulting material problems are correspondingly severe. Moreover, wall particles are released as impurities into the vacuum. When these impurities get into the plasma, their presence raises the energy transfer by radiation out of the reaction zone, cooling the plasma, causing plasma instabilities, and possibly killing the reaction.

In large vacuum chambers, whose construction poses no basic problems in space, the neutron flux density to the wall is reduced, among other advantages. Thermal stresses, blistering, embrittlement, and other damage are reduced. Maintenance problems are facilitated, and the useful life of the material structure is prolonged. With more internal volume available and with the high external vacuum, conditions are greatly improved for overcoming the impurity problem. Additional advantages (also for terrestrial fusion plants) may be derived from space-manufactured stronger (more homogeneous) refractory metals or other alloys suitable as inner wall material.

For use on Earth, a transmission system must be added to the energy unit. Through space, energy can be transmitted at any wavelength of the electromagnetic spectrum. But for transmission through the atmosphere, only selected wavelength regimes are suitable—primarily in the visible and the 10 to 15 cm wavelength microwave region. Transmission in the visible requires the redirection of sunlight by reflectors (space light). Microwave transmission must use large antenna arrays generating a coherent (i.e., laserlike, nonspreading) beam. Much smaller antennas are required if laser frequencies are used (for example, CO_2 laser light in the infrared). But they appear practical only for energy transmission into the upper atmosphere (e.g., to power aircraft at high-altitude level flight) but not to ground stations.

For Earth, the solar option is particularly enhanced by space light beaming to Earth the most versatile and ecologically best integrated energy source. The reflector size and number are tailored to their functional requirements—night illumination (Lunetta), power generation (Powersoletta), and photosynthetic food production enhancement (Biosoletta). Typically, Lunetta and Powersoletta circle Earth at 4200 km once every three hours, continuously in sunshine (sun-synchronous orbit). The large Biosoletta system preferably orbits in a slightly elliptic, 24-hour orbit, highly inclined to cause minimum, if any, interference with communication satellites in equatorial geostationary orbit.

Lunettas can serve urban areas, remote industrial activities, rural areas in developing countries to facilitate night work where needed, and disaster areas. Controlled light is provided to specific targets for specified periods without cables and fuel consumption. It can be delivered quickly, removed without a trace, or furnish reliable, high-quality urban lighting even at cloudly skies or in fog, without danger of blackout.

Present city lighting, averaged over the urban area, equals about that provided by two full moons high in a clear sky. Most outdoor lighting requirements correspond to an illumination equivalent to between 100 and 1000 moons, in farm areas 50 to 300 moons. A Lunetta system with clear-sky illuminance of 700 moons (over 100 moons even at strong overcast) needs some 3.6 sq km of reflecting area, divided into 15 to 20 reflectors. Since they move across the sky, additional reflectors must be installed, raising the total to 27 sq km, but

more than one city may be served. Individual reflectors appear as stars some 1500 times as bright as Venus—a beautiful sight, illuminating the city gently but distinctly from several directions.

Powersoletta enhances solar energy supplies to earthbound solar-electric central power stations. Reflectors (10 to 50 sq km) with a cumulative area of 1530 sq km beam one solar constant to a 1200 sq km ground area. Because of their motion, 11,500 sq km reflecting area must be installed. But at least three ground stations can be served in a latitude belt between 30 and 50 degrees. Powersoletta removes geographic constraints on solar central power siting. Latitude becomes comparatively less important than low-average overcast.

A ground station, at 1000 sq km of solar cell banks and 15 percent conversion efficiency, operates around the clock, yielding a net annual output of 45 to 65 million kilowatt-years, depending on local atmospheric conditions. Energy storage for baseload power is minimized. The output is of great economic and environmental significance. Over a three-year period, a 55-million kw-year annual output consumes 339 or 552 million tons of oil or coal, respectively; or requires a loading of 1807 metric tons of uranium in light water reactors, generating 63.2 tons of assorted fission products, 16.1 tons of plutonium isotopes, and 9.5 tons of long-lived waste.

People living within at least 50 km of the power station will experience night light intensity between midnight sun and bright aurora, due to light spillover. This could be avoided by operating Powersoletta at daytime. Certain reflectors are turned around to the Sun, beaming at those reflectors best positioned at the time to service the power station. The retroreflection technique may cut the reflecting area by some 30 percent. This technique requires extensive energy storage but no enlargement of the receiver area (the most expensive addition) because of double irradiation.

For the night Powersoletta, a cost at the bus bar of electricity (in 1977 dollars) of about 50 mils/kwhe is indicated during a 30-year amortization period, about 20 mils/kwhe thereafter. For the daylight system, 35 to 40 mils/kwhe and 15 mils/kwhe, respectively, are indicated. These numbers include a ground station cost of over $1000/kwe, twice the Energy Research and Development Administration (now Department of Energy) 1985 goal of $500/kwe.

The reflectors with adjustable facets use structures of carbon epoxy and fibers and membranes of kapton. All parts are coated in space with the optically best material, sodium. Recoated and serviced at about ten-year intervals, the reflectors should last 60 to 100 years. At a resulting sodium consumption of 1500 tons annually, a service station may be established at libration point L-4 or L-5 in lunar orbit, supplied with sodium mined on

the Moon (measured abundance in lunar samples 0.2 to 0.5 percent). The reflectors can commute to lunar orbit by a combination of solar pressure and electric thrust—in 300 days or less transfer time at a reflector weight of 75 tons/sq km.

To prevent night frost damage, Powersoletta excess reflectors can beam temporarily at the cold area to raise local temperatures and thereafter be reoriented to the power stations.

Biosoletta is applied most effectively to fertile ocean regions lacking sunlight for achieving full productive potential; that is, to circumpolar upwell areas. At some 100,000 sq km, the irradiated area should be ecologically self-contained. Seafood is a vital protein supplement. Based on Antarctic production figures and a 40 percent utilization factor of seafood produced, a Biosoletta alternating in 12-hour intervals between a 100,000 sq km "macropond" each in Arctic and Antarctic waters (50 to 70 degrees latitude) could generate an annual Antarctic yield alone of the daily protein supply (36 grams in about 220 grams of seafood) for 180 million people. Again, the Biosoletta reflectors can be serviced at a libration point to which they solar-sail in ten days to three weeks.

Even Biosoletta's energy influx constitutes barely 0.08 percent of the Sun's energy influx and, therefore, cannot affect the global climate. Locally, cold winds and strong currents dissipate the thermal energy rapidly. Biosoletta furnishes make-up radiation energy to power carbon assimilation. Solar radiation in polar regions delivers 0.7 trillion kilocalories per sq km per year, compared to between 1.2 and 1.6 trillion kg-cal/sq km year in tropical waters. Biosoletta "photon-fertilizes" two tiny but bioproduction-intensive "macroponds" (each about 1 percent of a 5-degree belt at 60 percent latitude) to approach the solar level at low latitudes.

Compared to Powersoletta, the microwave-type Space Power Satellite (SPS) alternative has a number of advantages and disadvantages. The advantages are reduced atmospheric losses, especially due to overcast, and the ability to shape the beam, thereby being able to irradiate relatively small areas from geostationary orbit; whereas a reflector's focal area increases with distance (barring costly special arrangements) and is about 100,000 km² from geostationary orbit. For this, however, SPS pays with greater complexity of its space component. The system must accept the primary energy, convert it to electricity, convert the electricity to microwave energy, and shape the microwave energy into a beam of required specifications. If the primary energy

is solar, the low-radiation density determines the system's size (80–120 km² for delivery of 10 million kilowatt at ground outlet) and its weight (50,000 to 75,000 tons for 10 million kilowatt), independent of the conversion system (photovoltaic or solar-thermal). For fusion as primary power, the waste heat radiator becomes the primary driver of system size and structural mass, depending on the conversion system. Generally, smaller sizes and weights are indicated. Powersoletta's thermal input, while far from critical, is higher, but a large number of microwave beams, each carrying millions of kilowatt power, may not be the publicly preferred option.

The disadvantages of the SPS are rooted primarily in the fact that microwave radiation at significant power densities is not part of the solar radiation input into the terrestrial environment. One consequence of this concerns ionospheric radio frequency interference, which causes power loss and can cause ionospheric heating. Through the limitation of maximum power intensity in the beam to about 17 percent of the Sun's radiation energy flux in the ionosphere (1.35 kw/sq m), this effect can be kept within acceptable limits. However, safety limits force the density at the beam's periphery to much lower values so that, including a safety zone around the receiver system, the required land area corresponds to an energy influx of about 2.5 percent of a solar constant on the ground (1 kw/sq m). For Powersoletta, the output per unit land area is about twice as large. Thus, SPS requires much more receiver land area than Powersoletta, even though the microwave beam can be shaped.

Space manufacturing looks commercially promising for a wide range of products. These lie primarily, but not exclusively, in the pharmaceutical, electronic, and optical sectors. In the pharmaceutical sector, it becomes increasingly desirable to separate and concentrate living cells capable of producing medically important substances. Under zero-gravity conditions in space, living cells, whose mass/charge ratios differ, can be separated efficiently and accurately by applying weak electric fields (electrophoresis). The effectiveness of this method is strongly impeded in the presence of a sizable gravitational force.

Electrophoresis has a wide range of medical and biological applications. An early promising use is the isolation of human kidney cells that produce the enzyme urokinase, a substance with the potential of effectively preventing and dissolving blood clots. Even at a present cost of $1200 per dose, the 500,000 doses currently needed annually in the U.S. alone cannot be produced by the present method that extracts one dose of urokinase from more than one ton of urine. The electrophoretic method can also be applied to separate other kidney cells that produce erythropoietin (an antianemia hormone stimulating the production of red blood cells in bone marrow); to a host of enzymes (blood proteins) controlling a wide variety of metabolic functions (and malfunctions); to white blood cells and antibodies (affecting tumor growth, transplant rejections, etc.); to chromosomes (X-, Y-types, affecting composition of cattle population through artificial insemination); and, possibly, to nerve cells (neurology). Even this list is not exhaustive. The consequences to medical and biological science and practice—from preventive, even predictive, medicine to agriculture—cannot even be estimated today.

In the electric/electronic product, value lies in the growth of mono-crystalline semiconductors of highest perfection and purity for a wide variety of applications. The same space features of null-gravity (eliminating convection currents in melts) and

ease of levitation melting (no contamination through wall contacts) also permit the production of glasses of very high purity and optical quality as needed for high-power laser systems, fiber-optic transmission lines, and high-resolution optics.

The list of already recognized potential products is much longer. All meet requirements of high value and low mass that give them commercial viability and could favorably affect the balance of payments of the United States and other industrialized nations vis-à-vis the rising costs of raw materials from developing countries. From there, other product lines lead to larger mass items and special products for larger space systems. In the larger mass items category, for example, is the production of new metal alloys and near-perfect, friction-free bearings and pistons by alloying metals of widely differing specific gravity (which causes them to separate at surface gravity), such as aluminum and lead alloys for bearings and pistons. Automobile manufacturers have long attempted at great expenditure to create such alloys that could give many automotive parts a capability of at least 500,000 miles. Two items exemplify the products-for-large-space-systems category: the aforementioned use of sodium for coating space reflectors and the production of ultra-light (for operation in a low-g environment) high-quality solar cells.

Lunar material contains industrially valuable materials. The world reserves of some of these appear limited at present. But several factors militate against major imports to Earth of zinc, copper, nickel, manganese, or titanium from the Moon (or from translunar sources, such as asteroids). In some cases, technological advancements will lead to the commercial exploitation of progressively poorer grades, thereby enlarging terrestrial land reserves currently not counted. Large mineral deposits become accessible on the ocean floor. Recycling and substitutions offer additional options for stretching terrestrial metal supplies. Job considerations in the primary (extractive) and secondary (refinement to semifinished products) metal industries are an additional factor since it takes a long time to phase out such industries, especially in developing countries, prior to relying on large-scale extraterrestrial imports. This leaves as a comparatively closer prospect the advantages of the lunar environment (vacuum, low-g conditions at the surface, zero-g in an orbiting lunar factory) for generating superior products of comparatively high market value but larger masses than those that are most suitable for Earth-orbiting factories. Access to low-gravity supplies can also be important for large space constructions as are typically involved in the energy sector. For these, however, the most attractive construction materials (graphite composites, graphite fibers, epoxies, poly-imides) are not available on the Moon. Therefore, the opportunities of taking advantage of lunar gravity to obtain construction materials for large space systems appear limited.

However, associated with the large masses of these systems are significant transportation requirements from Earth. If oxygen-hydrogen orbital transfer vehicles (OTVs) are used to lift these masses from near-Earth orbit (NEO) to outer, especially geosynchronous orbits (GSO), then, for each 100,000 metric tons of construction material delivered to GSO, the launch system must deliver also about 290,000 tons of oxygen to NEO for the OTV (plus 60,000 tons of hydrogen). For each ton of payload delivered to NEO, an advanced launch vehicle burns 11 to 15 tons of propellant in the atmosphere, releasing 8 to 11 tons of water vapor and 37,000 to 47,000 thermal kilowatt-hours. Whether the oxygen must be supplied from Earth, therefore, makes a difference of some 3.7 million tons of propellant burned in the atmosphere per 100,000 tons of cargo to GSO.

Lunar oxygen, therefore, can be an attractive substitute, especially since it ranks second in abundance behind silicon, and it can be

extracted in large quantities by means of fusion power and requires no further processing. Of course, the need for oxygen can be eliminated by employing electric or advanced nuclear propulsion. But each of these alternatives has its own set of disadvantages and problems that keep the use of lunar oxygen a competitive option, especially since a lunar oxygen industry opens up a lunar industrial capability whose implications are not restricted to transportation. Another potentially attractive early option is a lunar service industry with selective resource utilization, taking advantage of low gravity availability as well as vacuum conditions on the surface. A case in point is the libration-point service station for Soletta reflectors with sodium and other selective resources supplied from the Moon.

Thus, the industrialization of space offers a new dimension of technology and productivity with a vast scope of opportunities in terms of electronic services, solar energy for Earth for illumination, electric power and food production enhancement, space factories, space fusion, and lunar industrial potentials. However, a great deal of hard-nosed research and development and of pragmatic, balanced in-depth assessment is necessary of the many opportunities as they come up. There will be disappointments as well as pleasant surprises.

More profound and inspiring than the technology, however, are human and socioeconomic implications. Understood in the perspective of the Extraterrestrial Imperative, space industrialization is the crucible in which the seemingly irreconcilable problems that cause such profound pessimism in the outlook of many can be resolved. Earth and space become one through the intelligence and the creativity of man.

IN conclusion, let us take a brief look beyond. In the perspective of the evolutionary thrust of the Open World of Earth-space, exoindustrial productivity may be regarded as the first phase of extraterrestrialization, that is, the process of living in more than one world. The industrial facilities of this phase are Earth-related, directly or indirectly, as they should be. The people who make up the industrial teams in orbit or on the Moon are and remain terrestrials.

The people on Earth benefit from space industries. They are not asked to foot the bill for huge autarkical, colony-type factories housing thousands who, in turn, deprive terrestrials of even larger numbers of jobs.

The economic function of space industrialization is to generate jobs on Earth, not in space. Its most important international function is to assist in reducing the gap in the economic development of our global "North" and "South," *not* by lowering the standards of the North but by raising those of the South. This implies continued global industrialization. But as the world keeps industrializing, global competition for our country will increase and continue to erode the job base. Thus, for domestic as well as international reasons we need to open up a new industrial territory and make it work for people right here on Earth.

As the space industrial capability level and the skill of productive space utilization advance, the number of people living in space for a major fraction of their life span will grow. These people will develop new preferences as to g-levels and lifestyles no longer necessarily related to terrestrial physical or social conditions. They will "urbanize" their new worlds. Space stations and lunar abodes will become their primary home—Earth a place to visit or perhaps just to "experience" holographically, in the comfort of their gravity environment. The more antiseptic surroundings in space settlements could reduce resistance to diseases of those who live in them from birth. They may find the hygiene

of Earth just as hazardous as we would find the hygiene of medieval cities or ancient Rome. Still, some space-born offspring may migrate back. Those who stay will continue to diverge sociopsychologically from the ways of terrestrial mankind, as Americans have diverged from their ancestral countries. They will become the new *Homo Extraterrestris* who no longer needs Earth, hence does not wish to simulate its environment slavishly.

Their readiness to achieve sociopolitical and resource independence will grow with the psychology of their extraterrestrial motivations and their technological ability to create new worlds in their totality. This will lead to Androcell, not a colony of Earth, but a *sovereign, mobile neocosm*. Androcell is the new beginning, while back on Earth open-world conditions move toward a demographic and industrial equilibrium.

The Androcell phase is likely to follow the intermediate phase, exourbanization. Oversimplifying somewhat, one may say that exoindustrialization puts the machines and productive techniques into space; exourbanization introduces the human and biological elements; and extraterrestrialization integrates the two components into complete neocosms.

Each of the three evolutionary phases is justifiable by clearly identifiable prime objectives as well as by their impact in changing the consequence world. Each phase contributes to the capability *and* motivation to progress to the subsequent phase. In the third phase, we leave the harbor and emerge into the open sea of space, psychologically and socially speaking. Human history henceforth will pulse through many world-arteries that lose themselves beyond the horizons of our present perception in the trackless infinity of space and time.

The civilization of the Androcell is truly three-dimensional, not only because the design of Androcell utilizes purposefully all gravity levels between axis and periphery of the rotating systems; but, more important, because living awareness between worlds, and between surfaces and Androcells, plays itself out in three-dimensional space. Through exoindustrialization (production facilities), exourbanization (Astropolis, Selenopolis) and neocosms (Androcells), the human life form may be regarded as returning to the three-dimensional origin of all terrestrial life. The two-dimensional existence of Earth's land surface becomes an evolutionary benchmark wedge between the three-dimensionality of the finite oceanic womb from which life rose to the brightness of consciousness and the infinite cosmic womb in which it can rise to a level beyond our understanding.

· *La Jolla, California*

How a small group of adventurous women, and a million-dollar toilet, helped NASA take one giant step for womankind

BY BARBARA ROWES

HOUSEWIVES IN SPACE

PAINTING BY RALLE

Two and a half years before John Young and Robert Crippen first fastened their seat belts aboard the space shuttle *Columbia*, NASA slipped this ad into the classified pages of the San Francisco *Chronicle*.

TEST PARTICIPANTS SPACE TRAVEL PROJECT We need female paid volunteers ages 45-55 to take part in an experiment related to space travel. Nonsmokers preferred. Must be able to adjust to horizontal semiconfinement of 24-hour day.

It wasn't until the following afternoon, in an upper-middle-class section of Oakland, that a gray-haired housewife got word of what would be, for her, a fateful mission. Around 14:00 hours she happened to turn on her kitchen radio. "Whenever I season a chicken," the energetic, fifty-four-year-old Lynn Luthi says, "I get my inspiration from country and Western." Shortly afterwards station KNEW broadcast the ad as a public-service announcement. "The instant I heard the word *NASA*," she recalls, "it was the beginning of an immediate love affair."

With one hand on the chicken, she dialed NASA. Busy signal. She was undaunted. "I made up my mind to get in there if I had to sit by the phone for the next twenty-four hours." Two days later she was still getting a busy signal. "Even while doing my shopping, I was trying to call NASA, direct from the supermarket," she recalls with a smile.

For the first time ever NASA was actually recruiting women for a historic Earth-bound, exploratory mission at its Ames Research Center in Mountain View, California. The women weren't female astronauts or military personnel, but average women — housewives, teachers, corporate administrators, journalists, secretaries, nurses, and doctors. And they have paved the way for female astronauts who will shuttle into space in the near future and for women of all ages to fly aboard the space shuttle as passengers in the distant future.

These women, chosen from hundreds of candidates, are the unknown heroines of the Space Age. They all took part in a NASA study officially known as Shuttle Re-entry Acceleration

Reproduced from Rowes, Barbara. Housewives in space. Omni, v. 4, June 1982: 64, 66-67, 128.

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Tolerance in Male and Female Subjects Before and After Bedrest, but unofficially and affectionately dubbed Housewives in Space. As a result of the extraordinary stamina and spirit that they demonstrated, they proved conclusively that women, as well as men, have the "right stuff"—not only to survive but to thrive in space. They also added volumes of data to the skimpy body of research NASA had on women's adaptability to space travel.

Before April of 1977, when the first crew of women were unpacking their suitcases for their stay at the Ames medical facility, NASA had not investigated the physiological responses of women to space travel. In the weeks that followed they went through the same battery of tests given to a select group of men, tests designed to see how well they would withstand the crushing g-force of takeoff and reentry from space, the debilitating effects of weightlessness, and the challenge of performing coolly and efficiently in a state of total physical exhaustion.

The Ames medical study represents a major breakthrough in space development for the American woman. NASA has done hundreds of medical studies over the past few decades, but as late as 1972—years after the first Mercury mission—only one of these involved women, and that included a lone female subject.

It wasn't that women had been passively sitting back, contentedly Earth-bound, while men rocketed off into space. In 1962, three years after the Russians revealed they had already been training a female cosmonaut, a House of Representatives subcommittee held a little-noted hearing on sex discrimination and astronaut selection. On July 17, thirty-one-year-old pilot Jerri Cobb testified that NASA had tested 25 female pilots and had found 13—including herself—qualified to become astronauts. Cobb went on to excel at all the other qualifying tests, but she ultimately was caught in a military catch-22: NASA required that each potential astronaut be a test pilot, and female jet pilots were rare.

So for the next ten years Cape Canaveral, where astronauts roar beyond the *terra firma* of sex discrimination, was virtually a man's world. Although women played supporting roles as nurses, scientists, and engineers, they were always left waiting by the launchpad at liftoff. Their situation finally began to improve in 1972 when the government approved the budget for *Columbia*. By then it was taken for granted that at least one woman would be strapped into a shuttle seat sometime in the future.

Why were women, deemed fit for passage on the shuttle, but not in a rocket? "A lot of reasons were tossed around," says David Winter, formerly the director of life sciences for NASA, "but the main one was that until the shuttle came along, there was no way to manage women's waste. If you can't handle a basic physiological need like that, you can't go anywhere." And so on board the shuttle is the last piece of technology needed to liberate space: a $3 million, unisexual, zero-g toilet that accommodates the male and female anatomy. Equipped with handholds, footrests, and a seat belt, it uses a suction fan to simulate the gravity that makes toilets on Earth work so well.

Shortly thereafter Dr. Winter and his farseeing associate, Dr. Harold Sandler, chief of the Ames Biomedical Research Division, recruited 12 Air Force nurses, between the ages of twenty-three and thirty-four, as volunteers for the first study of female fitness for space travel. Although the experiment was limited, the results indicated that neither body chemistry nor anatomy interfered with a woman's capability to withstand the stresses of weightlessness. Encouraged by these findings, the NASA experts spent three years meticulously planning a more detailed medical study designed to see whether women were the equal of men in adapting to the stresses of travel to and from space.

NASA has done hundreds of medical studies over the past few decades, but as late as 1972 only one of these involved women, and that had a lone female subject.

This new study, unlike all the others, was to be co-ed. Winter and Sandler planned to spend five years putting three different age groups—each consisting half of men and half of women—through exhaustive tests on a rotating basis. In 1976 they began with the first group, thirty-five- to forty-five-year-old men, followed by a group of women in the same age spread. The project moved through the forty-five to fifty-five generation and on up to the fifty-five to sixty-five bracket. For four weeks members of each age group would go through a rigorous series of tests, similar to the ones conducted on astronauts, designed to reveal their ability, or inability, to withstand the special physical and mental demands of traveling in and from space. Though both sexes went through the same regimen, the attention was focused on the women who, for the first time in the history of the space program were really being tested seriously.

"When I stopped to ask myself why I wanted to do this so badly," Luthi recalls, "I realized that I wanted to find out whether I could endure those physical pressures and hardships that had challenged men but somehow never seemed to touch the sheltered lives of women." She had been a housewife for 20 years. "Now I was ready," she says, "to seize this opportunity at NASA to discover whether I really measured up physically."

Before the first female subjects arrived at the biomedical research facility, there was genuine excitement and anticipation about who the recruits would be. "We didn't know what kind of woman would volunteer," says manager Dee O'Hara, who has been flight nurse for NASA's manned space missions since the days of *Mercury*. "We thought it would probably be housewives, because they were the only ones with flexible enough schedules."

Actually they came from all walks of life. Bernice Robertson, fifty-five, for example, was chief of the children and youth unit of the California Department of Health. While she was driving to work at Berkeley, California, one morning, she heard on the radio that NASA was looking for adventurous women. "And at seven o'clock in the morning a *bed*-rest study sounded very appealing," she jokes.

Her job posed no problem. She was promptly granted a leave of absence and took some vacation days as well. Her husband, George, an administrator for an ambulance service, was another matter. "If you're going to be gone thirty days, who's going to cook for me?" he wanted to know.

Ever the dutiful wife, Robertson fixed up 30 meals, sealed them up individually, and popped them into the freezer. His meals then guaranteed, her husband became enthusiastic about her mission, so much so that he applied as a male subject himself. "We would have been the first couple," Bernice muses, "if he had made it."

It was twilight in Menlo Park, California, when Dale Graves returned home from the supermarket. She threw a steak on the broiler and settled into her teal-green swivel rocker to read a story about the space shuttle in the Palo Alto *Times*. A licensed pilot, a captain in the Naval Reserve, and a distinguished scientist at the Stanford Research Institute, she knew about the stories of female pilots who had taken the qualifying tests for astronauts and were mysteriously rejected. When she heard of the experiment, she called NASA.

Some women had problems, not in qualifying, but in bearing up under their families' unexpected resistance to their becoming NASA subjects. One of these was Arline Fitz[illegible]ld, a fifty-nine-year-old widow who was working as a court reporter for a municipal judge in San Francisco. She hadn't anticipated the strong opposition of her children. "They were dead set against it," she confides. "My daughter, who is a physician, knew enough about the procedures to be good and worried about my physical well-being." Her son was even more worried and adamant. "He told me if I was to go, he knew I would never come back," she says. But she applied anyway. "At my age you don't get many opportunities like this."

The women underwent an extensive screening process. "The only time I would actually discourage an applicant," says Lynn Dunham, who handled the phone queries at Ames, "was if someone asked me right out how much we pay. That signaled they were just looking for a job. And this is not a job, but a highly technical study." The pay, in fact, was only slightly above the minimum wage.

About half the women who called dropped out. Those who did make it to the interview were carefully rated for character, commitment, and even congeniality. "A little like the Miss America Pageant," Robertson observes.

The NASA interviewers wanted well-adjusted, interested candidates. "What we were looking for were mature, congenial women who seemed to have a real purpose in life," Dunham notes. The study was to be a group project, in which eight to ten women had to get along living together in cramped quarters for weeks. "You can't select a very nervous or egotistical individual. You can't choose someone who is a comic or a manic-depressive. Twenty-eight days confined with a woman cracking jokes or lying around with a chip on her shoulder can become very tiresome," Dunham explains.

Those who passed the selection process went on to the two weeks of grueling physicals and orientation. This would be followed by four to five spartan weeks of more tests and life without alcohol, cigarettes, caffeine drinks, or any medication — including vitamin pills.

"Some women were frightened by the physical demands and dropped out," says one who didn't, Donna Howell. She had retired from her job as an administrative secretary at age sixty-five. "It didn't faze me a bit." An outdoorswoman, whose pleasures include fishing and hunting with her husband on their property in Idaho, she plunged into the required physical with enthusiasm, and not a little apprehension, especially when asked to run the exhausting treadmill test. "It was the most intense physical I ever had in my entire life," she says. Once finished, however, she left for a relaxing vacation in Hawaii.

A few days into her trip she got a call from NASA to return for more tests. Even cutting short her holiday, she flew back to California. "I couldn't help wondering what I was letting myself in for."

Over the next two weeks she found out. Like all the women, Donna was spun around in a centrifuge to experience the crushing forces of gravity. She was dunked in a tank to be weighed under water, and she was wired from head to toe while her body was partly encased in a vacuum.

For some women it was traumatic, but for Dale Graves it was fun. "I enjoyed the other women so much and the challenge of every test. I knew I had to make it." Only eight to ten of the semifinalists in each age group would be selected after orientation.

At the end of the selection process the phones of the chosen women were ringing with a special message. When the call came to Arline Fitzgerald, she didn't answer. "I thought it was somebody bugging me for a transcript," she says. Late in the afternoon NASA telephoned again with the good news. She was accepted. "I had gin over ice with a twist of lemon to celebrate. I knew we'd have no alcohol for a whole month."

And so between April 13, 1977, and April 28, 1981, three different groups of women, between the ages of thirty-five and sixty-five — a total of 27 in all — reported to the NASA research center in Mountain View. They spent the next 28 days in virtual isolation. Like the passengers on future space shuttle trips, they were able to communicate with their families only remotely, in their case by telephone.

They were outfitted with biobelts that monitored their heart rate and deep body temperature. This involved wearing a small transmitter connected to an electrode and pasted over the heart. They also had to keep a rectal probe at all times. "Although we were aware of it — it isn't exactly natural — nothing hurt about it. The only problem was that it kept popping out," Graves says. The women also got their g-suits, identical to the ones that male astronauts wear, complete with their names imprinted over one breast pocket. "When you put it on, you couldn't help feeling a little closer to blastoff," Graves adds.

The women were under constant medical scrutiny as they went through a series of tests specifically designed to gauge the response of the female body to the stresses of space shuttle travel: changes in gravitational pressure, oxygen utilization, the effects of fatigue on performance level, and the stress of reentry. Their bodies were constantly being poked, stabbed, and tapped for various medical samples. Over the course of the study, for example, each woman had blood drawn from her arm 28 times. "Not at all pleasant," Fitzgerald says of the blood tests. "My veins got it so bad, they hid from the needle."

The women were often exercised to the point of exhaustion. In one phase of the test each woman lay on her back and rotated her feet, pedaling an exercycle overhead. "They made us work harder and harder," Graves remembers. "I felt like I was pedaling uphill."

In the performance simulator, they lay on their backs in a miniature cockpit, the instrument panel of an airplane spread out above their eyes. Experiencing the simulated turbulence of wind and rain, each woman was asked to take readings off the instrument panel while doing hand-eye coordination tests at the same time. "It was designed to test the effect of fatigue on performance capability," O'Hara says. Often it was scheduled after the women were exhausted from riding the centrifuge.

One of the stranger studies was the lower negative body pressure test in which the women lay in a cylinder, and the lower half

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HOUSEWIVES

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of their bodies was encased in a vacuum, causing blood to drop down to their toes. "It felt as if you were two different people in the same body," says Luthi. "Half of your body was going up a mountain, and the other half was down at sea level."

But of all the studies and exercises, it was the centrifuge that was the most memorable and hair-raising test. Outfitted with the standard g-suit, each woman sat in a small cabin mounted at the end of a long centrifuge arm. The arm was sent spinning faster and faster to increase the gravitational pressure. They went from 1.5gs (one and a half times Earth's gravity) to 2gs, and all the way to 3gs, even though pressures of more than 1.5gs are unlikely for future space shuttle passengers.

"You're seated in this chair, tilted back, and wired with electrodes on your arms, legs, and temples," Luthi explains. "There's a radio in there with you and a microphone. The scientists are giving commands and asking you questions. You're told to stare straight ahead at green and red lights overhead, and when they turn one on, you're supposed to flick it off with a switch. That way they test your alertness. By the rate of your response, they could tell whether you were going to black out," she continues. "At any point you can stop the whole thing just by pressing a button, but I wasn't going to end it under any circumstances."

What did it feel like? "At 1.5gs there was almost no pressure on me," Luthi says. "At 2gs I began to feel some, and at 3gs I felt this great force, pushing me deeper into the chair. It was very, very uncomfortable. First I felt like I was going to be squashed, and then I began to feel as if the lower half of my body was swelling up. At that point I honestly would have preferred to be walking my dogs."

Some of the women felt sick to their stomach at the 3g level. Others passed out. But no one quit.

"I felt, in a way, like a piece of meat," Luthi continues. "I knew I simply was a body they were testing. It's not like you're being used as a sex object. You're at the center of what everybody is doing. It's not a bad feeling."

On the tenth day the women went into another phase of the study—bed rest. The deconditioning effects of zero gravity, scientists have found, can be duplicated by lying prone for long stretches of time. So for ten days the women were confined to bed. While they were bedridden, they were not allowed to raise their knees, to lean on their elbows, even for eating, or to sit up in bed. No one was permitted to walk to the bathroom. "And when we wanted to shower," one subject recollects, "someone would roll us in a gurney over to a special horizontal shower, lift us up onto it, and then turn on the water. We called it the car wash."

Passing the time was not as tedious as it might seem. There were television sets and radios, and plenty of lively gossip to catch up on. Some women knitted afghans. Others wrote letters. During the blood tests several women nearly passed out. "We were a lot more vulnerable," Luthi says.

There were some adjustment problems. The women developed agonizing backaches, but those disappeared as their bodies got used to the tedium of bed rest. More lingering were the aftereffects of their time lying down. All felt weak and a little dizzy when they were finally helped out of bed after the tenth day. Many experienced aches and pains, the result of a slight amount of calcium loss. This was especially true of the more physically active women like Howell. "This is what happened to the very active astronauts when they came back," she explains. "Their blood vessels enlarged from the inactivity, and they felt lightheaded with pins and needles in their legs—like I did for two days after it was all over."

The five-year study produced reams of invaluable data, which NASA scientists are still studying. NASA has not yet published a final report, but last spring, even as the final group of women were packing their suitcases to head for home at last, researchers were already drawing some preliminary conclusions. Immediately evident was that the 27 women had done a superior job, compared to the men, of adapting to the physical and psychological challenges of the series of tests.

Moreover, the women had quickly bonded together into a group that was more cohesive and much more supportive than anyone at NASA had anticipated.

No shuttle passenger flights are scheduled now. The time for fun and adventure rides into space may still be 20 to 30 years in the future, but when the time comes for frequent space travel, the sex of the traveler will present few problems. These 27 women proved that. Dr. Sandler confidently predicts it is just a matter of time before trips to space become as routine for women as they are now for men.

Ultimately the study served to reinforce what many people had claimed all along. As a creature of space, the woman is clearly the superior sex. As pilot and would-be astronaut Cobb suggested in her House committee testimony 20 years ago, women are better physical candidates because they consume less food and less oxygen and because they are more radiation resistant.

In addition, Sandler notes, "One of the real disadvantages women have here on Earth is a direct result of the force of gravity. Because of gravity, they need strength and stamina to do hard work. On this level they cannot successfully compete with men." But in the world of zero g the brute strength of men means little. Because strength isn't as important, and because of the women's superior performance in the Ames study, Sandler predicts, "In space, women are going to beat men." ○○

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SICK IN SPACE

Aboard the shuttle you can't just lean over the rail—which is why scientists are searching for a quick fix for astronausea.

A small manila envelope bearing an ominous inscription is tucked into the pocket of my flight coveralls. I am hoping I won't need to open it, but I have reason to worry. The plane I am in, a military version of a 707, is used to familiarize astronauts with weightlessness, and over the years they have dubbed it the Vomit Comet. Its parabolic hops offer 25 seconds of free fall between brief onslaughts of twice normal gravity. With some 40 parabolas per flight, the ride can be a long one—especially if you are sick.

Two hours later, after I have floated in midair a total of 16 minutes, the manila envelope is still tucked neatly away. Weightlessness is so enjoyable, in fact, that I sign up for a return visit the next day. Yet for many who ride the Vomit Comet its name is well deserved. These days its passengers include physicians nearly as often as astronauts in one of the most intensive research efforts in the space program's history. The goal is to discover why four out of every 10 astronauts become motion sick during space shuttle missions.

Typically, the illness strikes an astronaut within 24 hours of lift-off, sometimes even in the first hour of space flight. The next two days can be uncomfortable, although astronauts maintain that their productivity is undiminished. Then, by the end of the third day, symptoms are usually gone. When Soviet cosmonauts are affected, they are given a chance to slow down for a few days until they have adapted to weightlessness. But shuttle mis-

by Andrew Chaikin • illustrations by David Lesh

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sions are far too costly for NASA to add rest days and too hectic to reschedule such important tasks as releasing a satellite for one of the agency's paying customers. With this in mind NASA has put several teams of motion sickness experts to work on finding a cure.

"Motion sickness has probably been with us since man invented the wheel—or the boat," says Millard Reschke, a scientist with the Space Biomedical Research Institute at the Johnson Space Center in Houston. The symptoms of this age-old malady are familiar to many who have endured rough seas or turbulence aloft. A victim breaks out in a cold sweat and turns pale. He may begin to salivate, then swallow, and what is euphemistically called gastric awareness may set in. Waves of nausea assail the unfortunate traveler, and finally he vomits, often repeatedly. Yet this very ancient, unpleasant by-product of travel is poorly understood. The space-borne variety is even more puzzling.

Motion sickness in space was first reported among American astronauts during the *Apollo 8* moon voyage in 1968. Mission commander Frank Borman became ill on the outward leg of the trip. Back on Earth, Borman refused to undergo any tests for motion sensitivity, and NASA said only that he had suffered a reaction to sleeping tablets. As former astronaut Russell Schweickart puts it, getting sick in space "wasn't the right stuff." Most astronauts still don't like to talk about it.

Schweickart, who experienced motion sickness during his *Apollo 9* mission in 1969, spent the next four to five years studying the problem with researchers—with little success. "I suspect even today," Schweickart says, "the medical community does not understand even the most fundamental question: Why does motion disturbance result in a vomit reflex?"

Researchers believe that motion sickness stems from a complex interplay of sensors that report to the brain on motion. They have given most of their attention to the vestibular system, which allows us to feel movement, to balance, and to sense our body's position. The vestibular organs, nested in the inner ear, have two main components—the semicircular canals and otolith organs.

The semicircular canals are narrow tubes filled with fluid; each has a door-like flap that registers motion of this fluid. They report every twist and turn of the head. In engineering terms, they are angular accelerometers.

The small sacs called the otolith organs, also filled with fluid, tell us literally what's up. They are the body's linear accelerometers, registering the constant force of gravity. When you lean your head to one side, gravity tugs at a layer of calcium carbonate crystals inside the otolith, causing the crystals

As former astronaut Schweickart put it, getting sick in space wasn't "the right stuff."

to shift slightly. Even with eyes closed, you can tell that your head is tilted, and in which direction, by the signals from your otolith organs.

Together the semicircular canals and otolith organs allow us to keep our balance while executing complex motions ranging from walking up a spiral staircase to dancing a waltz. But they can be fooled and can disagree with each other as well as with our other senses. Pilots have flown out of fog banks believing they were right side up, only to learn from their eyes that they were upside down. Some sailors continue to feel the sway of the deck even when they can plainly see they are back on shore. And during a rough sea or bumpy air voyage the vestibular organs register sharp motions, while the eyes are reporting that things look fairly steady. As far as anyone knows, it is this stream of conflicting signals to the brain that causes motion sickness on Earth. The "sensory conflict" theory has been popular for decades.

In space, sensory conflict arises from the effects of weightlessness on the vestibular organs. The fluid in an astronaut's semicircular canals has inertia just as on Earth; this allows him to feel rotations. His otolith organs, on the other hand, no longer have the constant tug of gravity on their calcium carbonate crystals. The combination of normal canal messages with abnormal otolith input is a form of sensory conflict peculiar to space flight.

When Schweickart returned from *Apollo 9*, he headed for the Naval Aerospace Medical Institute in Pensacola, Florida, where a physician named Ashton Graybiel was leading the field of motion sickness research. Schweickart was spun in a rotating chair to gauge his sensitivity to motion sickness. His ears were flooded with warm and cold water to induce the erratic eye motions called nystagmus that are associated with severe motion disturbances. And he rode again and again on the Vomit Comet, all so that some clue might emerge to why he was prone to motion sickness. There was none. In fact Schweickart was judged relatively resistant to motion sickness.

Today, 15 years since Schweickart began working with Graybiel, there is still no way to tell who will experience space sickness. Graybiel is still at work on the question, aided by his son-in-law, James Lackner of Brandeis University. Part of the problem, Lackner believes, is that sensory conflict involves more than just the inner ear. When you turn your head, sensors in the neck muscles are activated. Their data are processed in the same part of your brain as the messages streaming in from the vestibular organs about your head's motion and from your eyes on the changing field of view. In normal gravity, these different sets of data give you a consistent picture of the turn.

Still more information pours in from other sensors throughout the body. If you move your arm, your brain determines its position by processing data on the tensions of the arm muscles. When you sit down touch receptors in the skin sense the pressure of the chair. And you register pressure on the soles of your feet every time you stand up.

None of this information, which neurologists call the proprioceptive, is available in weightlessness. Muscles no longer fight against gravity. Nothing presses against a free-floating person. Astronauts have reported awakening from sleep in a darkened cabin and not being able to tell where their arms were.

In the absence of gravity, with the otolith organs unable to sense up and down and the proprioceptive inputs removed, an astronaut has only one means of sensing orientation — vision. If he never strayed from his spacecraft couch, that might not matter. But once floating free, he is more likely to align his sense of up and down with his body, no matter what the orientation of his surroundings. Lackner has even found on the Vomit Comet that a subject can change his sense of orientation drastically just by looking in certain directions — upwards as opposed to at his feet, for example.

So diverse are the various stimuli involved in this orbital variation of Earthbound sensory conflict that NASA stopped referring to space motion sickness and coined a new term, "space adaptation syndrome."

Lackner is the first to admit that 15 years of research have not brought him and his few dozen colleagues much closer to understanding space adaptation syndrome. He rides the Vomit Comet several times a year, along with his test subjects, but wishes it were possible to carry out his work in the cabin of the space shuttle. For the time being, he and other scientists in the field must rely heavily on another researcher who has that chance: William Thornton.

As an astronaut and physician, Thornton was the right man in the right place in late 1982, when NASA's concern over space sickness was at a peak. During the fifth shuttle flight, that November, astronaut William Lenoir's bout with motion sickness had delayed a spacewalk attempt, and the press gave the problem a great deal of attention. Despite Lenoir's postflight assurances that his work capacity was undiminished by the illness, the military was beginning to wonder if it could successfully use the shuttle to deploy its reconnaissance satellites on short notice. There was talk of a five-year research effort costing tens of millions of dollars. But the agency could not afford to wait for such a program. So shuttle planners added Thornton and fellow physician Norman Thagard to upcoming flight crews specifically to figure out what was making the astronauts ill—and how to stop it.

For Thornton it was the start of months of 20-hour days developing the instrumentation he would take with him on the shuttle's eighth flight, in August 1983. Some of the experiments would also be ready for Thagard to bring along on the seventh mission in June for valuable preliminary data.

When Thornton talks about space sickness, it is with a directness that sets him apart from other astronauts—and his approach to the problem is unique among researchers. "My interests are

One crew member threw up after noticing the Earth at an odd angle through the windows.

operational ones," he says flatly in his easy North Carolina drawl. "If I could find some new aspirin tablet that would cure this thing, and nobody knew why, I'd be the happiest man on Earth. I'd fold up my tent and go away."

NASA would like to see Thornton succeed, for the drugs most often tried against space motion sickness have been only partially effective. While Graybiel was extending the sensory conflict theory to weightlessness in the early '70s, he hit on a drug that had unprecedented success with his test subjects in preventing motion sickness both in normal gravity and in parabolic flight. It is scopolamine, an ingredient found in some cold remedies. No one knows why it works. It may block the chemical transmitters by which the vestibular system communicates with the brain, thus blocking signals of sensory conflict. Part of the ambiguity stems from the fact that these transmitters have yet to be identified.

But scopolamine has some undesirable side effects, among them drowsiness. For astronauts, Graybiel added the stimulant dexedrene, although space shuttle commanders, who would have to land the shuttle if a launch were aborted, are prohibited from taking the drug until after reaching orbit. A number of astronauts on the first five shuttle flights took scop-dex capsules before launch, with mixed results. "There isn't really enough data there to say anything about it yet," Reschke says. "But there is every reason to believe that it will be effective." But because of its side effects, it is unlikely that NASA would stick with scopolamine if something equally effective came along.

To Thornton, the effectiveness of scopolamine on the ground, on which Reschke's optimism is largely based, is beside the point. Space motion sickness, he says, is wholly unlike its Earth-based counterpart. Researchers have been severely limited, he feels, because "they used traditional methods of making people sick and tried to extrapolate from that. If you think you can produce the effect by putting somebody in the chair and making him sick, you are badly deluded."

Before his own mission, Thornton interviewed fellow astronauts upon their return from space; their comments reinforced his feeling that something unique was happening. Many of the hallmarks of ordinary motion sickness—sweating, pallor, and even nausea—were frequently absent. Loss of appetite and a knot-in-the-stomach feeling were often present. And curiously, they reported, when they vomited it was often without warning. One crew member threw up suddenly after noticing the Earth at an odd angle through the shuttle's windows.

From this information Thornton suspected the digestive tract was somehow affected by weightlessness, and he added abdominal studies to his growing agenda for the August flight. When Thagard lifted off on his mission, the schedule included a request from his fellow astronaut. "I asked Norm to look carefully at the stomach, and he did," says Thornton. "He also took the time to listen." Why listen to the stomach? In a normal person on Earth, the digestive tract is in near constant motion; it can be heard with a stethoscope. Thagard returned with some important news: When his crewmates were ill, their digestive tracts were quiet.

That could explain why vomiting sometimes comes on so suddenly, Thornton reasoned. With the normal digestive motions ceased, the stomach would eventually fill up. Then it would send distress messages to the so-called emesis center of the brain, where the vomit reflex originates. With loud distress calls already pouring in from the confused vestibular organs—due to the canal-otolith sensory conflict—the first message from the stomach would push the emesis center over the edge—perhaps too quickly for nausea to set in. This is in strong contrast to vomiting on Earth, in which the stomach sends no such "trigger" signals to the brain.

When Thornton and five crewmates left Earth on August 30, 1983, Thagard's results were very much on his mind. But Thornton had developed another theory about what he would find. In zero gravity the body's fluids migrate headwards, which makes astronauts' faces puffy after a few days in orbit. Thornton felt that fluid would probably build up in the inner ear, causing a condition similar to Meniere's syndrome, whose victims experience dizziness, nausea, and vomiting. It might well be this fluid buildup that causes space sickness, he reasoned.

As soon as *Challenger* reached orbit, Thornton was at work. "I learned more from the first hour and a half in space," he said after his return, "than from all my literature searches." While his crewmates attended to their flight plan, Thornton, wired with electrodes on his eyes and skin, labored under his own hectic schedule. He barely stopped to eat. He seemed to move from one test to another in a blur of wiring and electronic gear that reminded the others of "an explosion in a Heathkit factory." When the five days were up, Thornton had changed his mind in a big way.

"I had to eat a lot of crow," Thornton admitted. "I had been opposed to calling it motion sickness. I am now willing to say that it is a form of motion sickness, but vastly different from anything experienced before." Thornton could speak as much from personal experience as anyone. NASA regulations prohibit him from disclosing individual symptoms, even his own. Reportedly, however, he felt the rapid onset of motion sickness early in the flight as he moved about within *Challenger*'s cabin. Confirming what Lackner had discovered during parabolic flight, Thornton found that nodding the head up and down is particularly sickening.

When Thornton had time to examine his data, there were more surprises. His tests disclosed no signs of fluid buildup in the inner ear, as he had theorized. There was no evidence that vision was distorted. No overwhelming signs emerged that lack of proprioceptive information played a decisive role; devices designed to induce the normal muscle tensions felt in one g had no ef-

fect. (Reschke, however, wonders if, later, more precise measurements than Thornton was able to perform might change some of these results.)

Interestingly, Thornton learned as much from his stethoscope as from his "Heathkit factory." One of his most informative activities was conducting in-flight physical examinations of his crewmates. These confirmed Thagard's findings of a quiet digestive tract. Thornton was prepared: He had brought along a drug to set the digestive tract in motion again. Though Thornton isn't telling for now, the drug is probably related to metachlopramide, which is commonly used for such purposes. Crew members who took it during motion sickness got quick relief from nausea, they didn't vomit again, and their appetites came back.

Some symptoms—headache, general malaise, and sensitivity to such motions as nodding the head—persisted. A truly successful "operational solution" will have to cure these symptoms as well. What's more, astronaut Byron Lichtenberg, himself a motion sickness researcher, later tried the drug during the first Spacelab mission last fall, with no benefit at all. Still, for the crew on Thornton's flight, the digestive drug appeared to eliminate one of the most unpleasant—and, for spacewalkers, one of the most hazardous—effects. "It's not a complete cure," Thornton says, "and it remains to be proven. But it may be an important breakthrough."

Thornton will have a chance to continue his work in space late this year when he will fly again on the shuttle, this time with the roomy Spacelab module along for extensive research. While he tries to confirm the success of his digestive drug and nail down the "operational solution," earthbound researchers like Lackner will continue working for a broad and fundamental understanding of the problem.

"The more you pick at it, the more complicated it is," Lackner says wistfully. It may be a decade or more before he and his colleagues find what they're after, and by that time NASA's proposed permanent manned space station could be operating. With astronauts spending six straight months in a weightless environment, Lackner reminds us, motion sickness will be only one of a host of complex physiological problems encountered, including radiation exposure, potential weakening of heart muscles, and Lackner's own special interest, reflex and coordination problems due to prolonged weightlessness. "That's why my world won't end when space sickness is solved," he says. "It's just going to start."

Andrew Chaikin, an editor of Sky and Telescope, *writes regularly about the shuttle program and planetary exploration.*

Space Travel Is No Joyride

BEHAVIORAL METHODS MAY ALLEVIATE SOME OF THE DISCOMFORT THAT ACCOMPANIES WEIGHTLESSNESS.

BY CHRISTOPHER JOYCE

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If NASA were to choose you to ride the space shuttle, the chances are almost 50-50 that one of your first experiences in space would be throwing up. Many astronauts have, although NASA doesn't like to talk about that since some crew members find it embarrassing. And along with that upsetting factor there are other undesirable effects of weightlessness—lethargy, lack of appetite, drowsiness, stomach awareness, malaise, cold sweat and nausea. These are part of "space adaptation syndrome," or space sickness, the number one medical concern of space agencies of both the United States and the Soviet Union.

Behavioral and biomedical scientists at NASA have always been intrigued by the effects of weightlessness on the human nervous system, much to the chagrin of those astronauts who'd rather just fly than play orbiting guinea pig. But now that NASA plans to build and permanently man an orbiting space station by the early 1990s, solving the mystery of space sickness has taken on a new urgency. Not only will men and women be in space for unusually long periods, many will be shuttling to and from orbit for brief periods that won't allow them time to adapt to weightlessness.

Astronauts are a "gritty" bunch, says one scientist who has worked with them and once applied to be one. That is, they grit their teeth and get on with their work, smiling for the cameras while bobbing like bubbles in a lava lamp. But space sickness has played havoc with work schedules on at least two shuttle flights. During the third shuttle journey, much of the third day's schedule was pushed back because both crew members were sick. During the first few days of the Spacelab flight last December, experiments on crew members already woozy from moving around in zero gravity made them ill, and tight schedules were again disrupted.

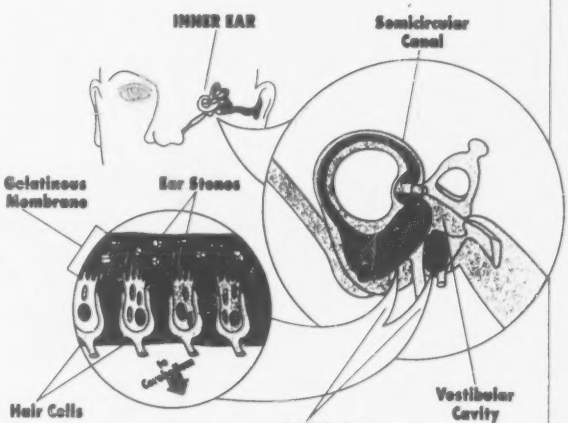
NASA can't afford to have astronauts suddenly calling in sick from 150 miles up, so a laboratory dedicated to the study of space sickness is being

Bruce McCandless II, outside the Challenger.

IT'S IN YOUR EAR—YOUR INNER EAR

The inner ear's vestibular cavity is the point of entry for the signals that tell us where we are and how we move. Linear motion and the constant force of gravity are sensed by the inner ear's otolith ("ear stone") organs, which contain calcite crystals that lie like a carpet on a sensory membrane in the labyrinth of the inner ear. If you sit motionless, the otolith registers gravity alone; linear movement (forward, backward or up and down) and acceleration cause the crystals to shift and move the hair cells on which they sit. These send signals to the cerebellum and brain stem, which perform the complex job of making sense of these signals.

Another element of our internal guidance system consists of three tubes in the inner ear called the semicircular canals. These narrow pipes contain fluid that moves through the canals when you rotate your head, and signals rotational or angular movement. —*C. J.*



NINA WALLACE

set up at the Johnson Space Center near Houston. Eventually, researchers hope to discover how weightlessness warps one's perceptions of position and motion and causes space sickness. In the meantime, psychological remedies, such as biofeedback and relaxation therapy, are promising candidates to augment the powerful but unpredictable drugs usually given queasy crew members.

The study of space sickness is so new—fewer than 150 people have flown in space—that researchers have just begun to track down its causes. One early hypothesis, popular among Soviet scientists, was that the upward shift of body fluids during gravity-free flights might be the culprit. That theory gave rise to cumbersome "negative pressure" suits cosmonauts wore over the lower body to draw blood back down to where it belongs. Scientists have abandoned that notion, however, and have decided that space travelers suffer from the same malady that laid low Lord Nelson, Napoleon and, astride his "ship of the desert," Lawrence of Arabia—motion sickness.

Space sickness is now believed to be an attack by the senses on the body's motion-control mechanisms, located primarily in the vestibular organs in the inner ear (see box). Much of the research on space sickness has been done at the Massachusetts Institute of Technology's Man-Vehicle Laboratory. There, in a veritable chamber of scientific horrors, researchers spin, rotate, drop and otherwise confuse subjects, who get sick and then adapt. Associate director Charles Oman should know the symptoms when he sees them: He is a veteran of offshore sailboat racing and has seen his share of pitching decks and bouts of what Australian sailors call "laughing at the ground."

BIOFEEDBACK AND RELAXATION THERAPY MAY AUGMENT THE DRUGS USUALLY GIVEN QUEASY CREW MEMBERS.

"When you move your body, the brain has learned what sensory signals to expect from the vestibular organs," Oman says. "It compares the expected to the actual. When it sees a difference, it says to itself, 'Ah, something new here,' and it triggers corrective movements." In space, however, the inner ear's otolith organs are confused by what they sense because they miss the effects of what has been their constant companion since birth—gravity. Meanwhile, the semicircular canals still sense rotational rolling and pitching head movements accurately, since their perception isn't affected by gravity, but what they sense doesn't agree with what the otolith organs sense. As a result, Oman explains, the signals sent by the vestibular organs to the brain do not match the blueprint drawn on the basis of earthbound experience. In short, what you see is not what you get.

The result is space sickness. At first, there may be a dizziness. Soviet cosmonauts recall feeling as if they had been turned upside down. As the

C. Gordon Fullerton floats in zero gravity: The body can't tell up from down.

space travelers unstrap and move about the cabin, they turn and move their heads, which generally brings on the more serious symptoms, nausea and vomiting. NASA's scientists have observed that rapid head movements are the surest way to create space-motion sickness; their observations are borne out by the increasing frequency of this sickness as space vehicles grow larger and give the crew more room to move about. This was especially true during the first flight of Spacelab, when the crew had to move around the cabin a lot, setting up the lab and various experiments. This extra movement, early in the flight, may explain the sickness some crew members experienced.

Why the nausea and vomiting? One possible explanation is that when the inner ear's vestibular system is overloaded or confused by weightlessness, there is a spillover that affects the brain's nearby vomiting trigger zone. Kenneth E. Money, a physiologist with Canada's Defence and Civil Institute of Environmental Medicine, proposes another theory: The brain receives mismatching information when poison enters the body. It responds by inducing nausea and vomiting to get rid of the poison. Since space sickness also yields mismatching information, the brain responds to it in the same way.

THE CONTRADICTIONS CREATED BY MOVING AROUND IN ZERO GRAVITY ARE UNRELENTING.

In space, the vestibular organs get no relief: The contradictions created by moving around in zero gravity are unrelenting. Were it not for the brain's flexibility, space flight might be as arduous for astronauts as ocean travel was for Charles Darwin, who never overcame seasickness during his voyage aboard the Beagle and who wrote as eloquently of his suffering as he did of Nature's exotic creations.

Fortunately, according to Oman and Larry Young, director of the Man-Vehicle Lab, the brain learns to compensate: It either ignores or, more likely, reinterprets signals from the otolith organs and puts more trust in the visual input it receives. Oman cites seasickness to illustrate this idea: Below deck, with no visual cues to prepare you for the pitching of a boat, you suffer more from your perplexed vestibular system than you do on deck. For much the same reason, pilots and automobile drivers, who are in control of their vehicles and therefore generally know what to expect, don't usually get motion-sick; their hapless passengers do.

Young, Oman, Money and Canadian researcher Douglas Watt tested these hypotheses on the crew of Spacelab during an ambitious investigation of space sickness. They had the help of one of their former students, Byron Lichtenberg, a biomedical engineer who earned a degree at MIT studying the vestibular system and then won a seat aboard Spacelab.

Young's so-called "dome" experi-

ment requires an astronaut to peer into a rotating drum that fills the field of vision with rotating spots. On Earth, this creates the uncanny sensation that you, the viewer, are rotating in the opposite direction, or that the room is spinning, much the same way you feel if you whirl around like a dervish and then stop suddenly. On Earth, the vestibular organs, which aren't actually in motion, don't corroborate this induced sense of body movement and thus help damp the sensation. Things work differently in space.

The "completely unexpected" finding in space, an excited Young told reporters at mission control in Houston, was that the sensation of rotating was grossly exaggerated aboard Spacelab, suggesting that the vestibular system had difficulty damping the sensation. Young stresses that his findings are still preliminary, but he argues that in space the brain may learn to rely less on the vestibular system and more on visual stimuli. If this is the case, then adaptation to weightlessness occurs because the brain gradually stops listening to the confused vestibular system and begins to rely more on the visual system.

Once acclimated to weightlessness, most space travelers aren't troubled by motion sickness, as those films of astronauts performing seemingly endless somersaults testify. But another familiar picture from space lore—that of beaming crewmen disembarking from another long flight, kicking the shuttle's tires and waving to the crowd as if they'd merely driven around the block—is simply false.

ADAPTATION TO WEIGHTLESSNESS MAY PERSIST AFTER LANDING AND CREATE EARTH SICKNESS.

Reports from the Soviet Union tell of cosmonauts who, after several months in space, had to be carried from their spacecraft; their cardiovascular systems, adapted to weightlessness, couldn't support the strain of gravity. Scientists are also finding that the vestibular system's adaptation to weightlessness may persist after landing and create, in some cases, "Earth sickness."

At NASA's Dryden flight-research center in California, the Spacelab astronauts were closeted from public view for several days as scientists watched their readaptation to gravity. "We saw some very interesting and bizarre postflight sensations," Young reports. Gazing into the dome, one crew member felt as if his body had tipped forward 90 degrees and were rotating like a pig on a spit. Others had trouble turning corners cleanly or saw the Earth spin when they jerked their heads. Some who had easily performed a "rail test" (walking with eyes closed along two narrow rails) before the flight fell off the rails after returning from space, buttressing Young's notion that the eyes had become more important, relative to the vestibular system, in the astronaut's sense of balance. "It isn't until you do fine tests that you see that they (the returning astronauts) are not really in such good shape," Young concludes.

Perhaps most dramatic was Money's postflight test in which astronauts were taken up in a KC-135 military transport and re-exposed to weightlessness during short parabolic flights. Violent head movements that made some of them ill before and early in their Spacelab voyage now had no effect, suggesting that the brain was still stuck in zero-gravity gear. The more time spent in weightlessness, the more difficult readaptation is; indeed, some Soviet cosmonauts have been ill for days after long flights.

Adaptation to weightlessness takes time, and this can cause problems in space, especially on short flights. "We

are beginning to pay a lot more attention to the degradation of performance caused by space-adaptation syndrome," says Jerry Homick, who has managed NASA's space-sickness research program, now at about $4 million a year, for the past decade. What's needed is a way to prevent or at least lessen the effects of space sickness early in the flights. NASA has thus far relied mostly on drugs, especially a mixture of scopolamine and Dexedrine. Scopolamine is a common anti-motion sickness drug. Dexedrine is added to counteract its soporific effects. Homick considers drugs an imperfect solution because their side effects can impair performance.

A more controversial but perhaps more promising antidote to space sickness is biofeedback coupled with "autogenic training." Patricia Cowings, a psychophysiologist at NASA's Ames Research Center near Palo Alto, California, pioneered the use of this technique with astronauts. Cowings is known affectionately to the astronaut corps as "The Baroness of Barf" ("I guess that's a compliment," she says), a title she earned by making people sick so she could learn how to make them well.

"Back in 1973, NASA knew it had a problem. Biofeedback was thought to be 'mystical,' but they were willing to try anything," Cowings recalls. Because astronauts' training time is precious, NASA told her to come up with a program that would take no longer than six hours. During this time astronauts were supposed to learn to control the physiological symptoms associated with space sickness and thereby control the sickness. Cowings designed a program of 12 half-hour sessions combining autogenic training—"a series of self-suggestion exercises, or a method of getting people to focus attention on a part of their body"—with biofeedback. During autogenic training, she teaches a subject to mentally evoke a sensation, like warmth in a limb or relaxation of muscles, to bring about desired physiological changes such as increased skin temperature or relaxed muscles.

Cowings' brand of biofeedback involves learning to control as many as 20 physiological functions related to motion sickness. These include such things as heart rate, skin conductance, depth and rate of respiration and the flow of blood to the hands. Subjects learn to regulate these autonomic functions by watching them as they are displayed numerically and on an oscilloscope. Cowings uses auditory tones to tell subjects when they begin to lose control of a particular function, or simply tells them herself. "The ex-

perimenter is like an orchestra conductor," trying to focus a subject's autogenic abilities on those autonomic functions that normally react first to motion, Cowings explains.

After the first four sessions, a subject rides a rotating chair to see if he has improved his control of the symptoms. Then it's back to the feedback machine. In the course of the program, subjects learn to manage the symptoms without feedback data and under distracting conditions; eventually they can control body functions crucial to motion sickness under trying circumstances, such as those aboard a spacecraft.

During the third flight of Spacelab, scheduled for November, three astronauts trained by Cowings will test her method, which has worked well on the Earth. For several upcoming flights, Cowings will dress her subjects in what she calls "the latest in astronaut underwear" and record several of their autonomic functions. The astronauts will also have biofeedback units strapped to their wrists, so they can monitor themselves.

Leonard Gardner, a clinical psychologist at the Johnson Space Center, is another believer in the behavioral approach to curing motion sickness. At the Air Force School of Aerospace Medicine in San Antonio, Texas, Gardner showed skeptical officers that he could salvage flight-training washouts, who had failed all other attempts to control their air sickness. Gardner trained 50 air crewmen in biofeedback and autogenic techniques and succeeded in returning 44 of them to active flight training.

Gardner's approach differs from Cowings'; he hooks his subjects to biofeedback equipment while they are spun in rotating chairs. In the early stages of his two-week session, the pilots were encouraged to take their minds off what they were doing. "One guy remembered practical jokes he had played on people," Gardner recalled. "He'd be up there in the chair, smiling and chuckling away. And after he had finished, he'd come down and say, 'Hey, what happened up there?' " Gradually, the subjects dropped the "thinking-good-thoughts" technique and instead concentrated on slow, diaphragmatic breathing.

"Many people are skeptical about behavioral training," Gardner remembers. "They say, 'This stuff isn't supposed to work,' and a lot of people, the 'I-eat-nails-for-breakfast' type, look on people with motion sickness as being weak. We encountered a lot of squad commanders with this attitude." Nor are pilot trainees the best subjects; Gardner says most of them are aggressive, proud and ambitious. "These people are usually uncomfortable with relaxation training," he points out. "Many of them never know how to relax. Their response has been to try harder and grit their teeth," just the wrong thing, he says, for combating motion sickness.

But the era of the gritty test pilot in space is ending, and NASA will need a broad range of expertise to build a permanent station. Clearly the human mind and body can function in weightlessness, but travel in space can have its side effects. Now that space travelers are performing complicated tasks, rather than simply being research subjects or "monkeys in a can," space sickness may prove to be a serious obstacle. As NASA and the Soviets contemplate colonies on the moon, and perhaps extended travel beyond, psychologists will become as important as engineers and physicists in preparing humans for the ultimate frontier. ☐

Christopher Joyce is a freelance science writer in Washington, D.C.

F. PLANETARY EXPLORATION

Mission to Mars: The Case for a Settlement

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BY CAROL STOKER AND CHRISTOPHER P. McKAY

The time has come–again–to plan for manned expeditions to Mars. Had a NASA mission begun as suggested for November 1981, these astronauts would have returned to Earth this past August.

HISTORY will undoubtedly record the Apollo moon landing in 1969 as one of humanity's greatest achievements. That journey was a giant step forward for humankind, proving that we could explore space and expand beyond our home planet. The ensuing 15 years of sustained activity in space have totally changed our perspectives of this frontier. It now seems obvious that people will live in space, but questions remain on when, what we will do there, and how we will get there. We must decide what the next step will be.

Over the last two years, a grass-roots organization of planetary scientists and engineers has made a case for establishing a permanent settlement on Mars as the next major initiative in space. Sounds bold? So did the moon landing a generation ago. In many respects, the incentives for a Mars settlement are the same.

In the future, as in the past, the nations that explore and expand the new frontier will be preeminent. A permanent settlement on Mars would provide a focus for developing space and help stake the U.S. claim to that frontier. It would assure the country a dominant role in deciding how people develop and utilize the solar system, whether by mining mineral-rich asteroids, manufacturing products in the microgravity or vacuum of space, defending national interests, or broadening scientific understanding. Settling Mars would give the United States a strong voice in shaping space law and treaties and guarantee its international prestige.

Why Mars? Public fascination with the Red Planet is legendary. From Percival Lowell to H.G. Wells, turn-of-the-century writers so vividly described life on Mars that lay readers assumed that an advanced civilization lived there. Much of the speculation was fueled by the Italian astronomer Giovanni Schiaparelli, who published many detailed maps of Mars in the 1890s. Among the features he described were straight lines connecting darker regions across intervening light areas. Schiaparelli called these markings *canali*, or channels, which became the famous "canals" of Mars when translated into English.

CAROL STOKER is a research associate in the Laboratory for Atmospheric and Space Physics at the University of Colorado in Boulder. Beginning in January, she will be a fellow in the Advanced Study Program at the National Center for Atmospheric Research in Boulder. CHRISTOPHER McKAY is a National Research Council fellow at NASA Ames Research Center in Moffett Field, Calif. The authors were coorganizers of the Case for Mars conference in 1981 in Boulder.

As rocket technology developed, the dream of reaching Mars entered the realm of possibility. For space pioneer Robert Goddard, the exploration of Mars was a long-held goal, and Wernher von Braun, the architect of the Apollo program, viewed the lunar landing as the first step toward a manned flight to Mars.

Of all the planets, Mars is the most hospitable and similar to Earth. Mars is the only other planet in the solar system with both an atmosphere and an accessible surface. Mercury has no atmosphere and is too close to the sun to permit human habitation. The surface temperature on Venus is 460°C—above the melting point of lead and much too harsh to allow a manned landing. By contrast, temperatures on Mars range from -120°C on polar winter nights to a high of 20°C in the southern hemisphere in summer. Unlike the giant planets Jupiter, Saturn, Uranus, and Neptune and their moons, Mars is close enough to Earth for people and materials to reach it within nine months, a reasonable time.

Unlike the moon, the only other candidate for a settlement, Mars is abundantly endowed with all the resources necessary for developing a self-sufficient base. Absent on the moon, water occurs in small quantities in the martian atmosphere and soil and in large quantities in the polar caps. Water is the most important compound needed. In addition to sustaining life, it is a source of hydrogen atoms, which are needed for chemical fuels, including rocket fuel, as well as for building materials and other useful compounds.

Mars also has the resources to produce life-support materials such as air, food, fuels, fertilizers, and building materials, eliminating the huge cost of transporting them from Earth. Although the martian atmosphere is thin—only 0.6 percent of the sea-level atmospheric pressure on Earth—and is mostly carbon dioxide, it can be processed to obtain oxygen to make breathable air. The atmosphere also contains argon and nitrogen, which may be used as a buffer gas in breathable air to inhibit combustion. Martian soil is 40 percent chemically bound oxygen, an-

other potential source of this important element. The soil also contains sulfur and chlorine as well as the metals sodium, magnesium, and iron. Thus, construction materials, fuels, and soil for growing plants can be manufactured on the planet.

In addition, Mars holds such a strategic position within our solar system that it may one day be regarded as the St. Louis of space. Mars is the gateway to the outer solar system and the main belt of asteroids between Mars and Jupiter. Asteroids are solar-system debris that were not incorporated in the formation of the planets. Some are rich in iron, nickel, and possibly other elements that are relatively rare on Earth. Other asteroids may be rich in volatile compounds such as carbon, oxygen, and hydrogen that can be used to make breathable air and fuels for future space-based operations. The two moons of Mars, thought to be asteroids captured by the planet's gravitational pull, could be critical proving grounds for asteroid mining techniques.

For scientists interested in planetary evolution, Mars remains a source of fascination. Despite the experiments performed by the Viking mission in 1976, the question of whether life exists on Mars has still not been completely answered. Even if contemporary life forms are absent, perhaps life evolved in a past, more hospitable climate. Mars offers a rich field for planetary biologists to explore.

Over a decade ago, NASA actively studied and planned a manned mission to Mars. The idea lost support when the agency's funding was cut back, but it is now drawing renewed interest. George Keyworth, the president's science advisor, recently suggested that it was time for the United States to think about new directions for the space program as ambitious and bold as the Apollo program. A Mars settlement would certainly qualify. Moreover, establishing a long-range goal for the space program would help ensure continuity in funding and widespread popular and political support. Such continuity has been sorely lacking in the U.S. program over the past decade.

Given recent advances in technology, a single manned mission could be staged for one-half to one-third the cost (in 1981 dollars) of the Apollo program. Such a mission would make use of the space shuttle and the proposed space station, projects that top NASA's priority list. With these and other projects under development, the Mars settlement is within reach of today's technological capabilities. Given a firm national commitment, we could be there by the beginning of the next century.

Scouting the Planet

The first step in planning a martian settlement is to investigate the planet's natural resources. Although the 1976 Viking mission to Mars returned a wealth of data about the planet, scientists lack the detailed information necessary to select a site for a permanent base. Such a site must be close to water, fuels, minerals, and building resources and situated so that reliable communications can be established with Earth. The site must also be close to scientifically interesting regions, and be flat and solid enough for a spacecraft to land.

Although water, a key resource, is present on Mars, it is scarce compared with Earth's supplies. The only large known sources of water are the polar caps, but they are not ideal locations for a manned base because of extremely low temperatures and constant darkness during winter. However, scientists believe that large reservoirs of underground water in the form of ice or permafrost may extend to Mars' lower latitudes. The small amount of water vapor in the atmosphere—0.3 percent—is also a potential source of water.

The surface of Mars can be mapped for water and mineral resources at low cost with a spacecraft that orbits the planet's poles. NASA has already designed such a mission, called the Mars geoscience/climatology orbiter. It carries a gamma-ray spectrometer—an instrument that records emissions from radioactive isotopes and from the interaction of cosmic rays with atoms in the planet's surface soil to determine its composition. Atmospheric water vapor will be measured by detectors tuned to look at the infrared emission and absorption features of water. NASA estimates that the mission will cost $100 million—by comparison, the Viking mission to Mars cost over $2 billion. Costs will be low because the experiments take advantage of technology developed for other missions, and because the spacecraft itself is based on production-line satellites for orbiting Earth.

Once prospective base sites are identified, samples of martian soil should be collected and returned to Earth for analysis. Samples could be obtained by unmanned vehicles or by a temporary manned lander, just as lunar samples were collected. Scientists can analyze these materials on Earth and then devise manufacturing processes to take advantage of them so that initial manned missions can begin manufacturing immediately.

The natural resources available on the two martian moons, Phobos and Deimos, deserve attention as well. If the moons are asteroids, then they may contain valuable, even rare, minerals unobtainable on the surface of Mars. Dr. S. Fred Singer, professor of environmental sciences at the University of Virginia, suggests establish-

ing a manned "beach-head" on one of the moons before attempting a landing on the planet. From this base, astronauts could operate a fleet of remote-controlled rover vehicles to collect soil samples from Mars. One advantage of such a plan is that it avoids contaminating Mars with terrestrial organisms and Earth with martian organisms—if they exist.

Outfitting the Ships

The trip to Mars would use both the space shuttle and NASA's proposed space station for a transportation network. A manned space station in low-Earth orbit with facilities for building structures in space is a key intermediate step on the path to Mars. The size and complexity of spacecraft needed to build the Mars settlement will make it difficult if not impossible to launch them preassembled from the ground. Instead, spaceships will have to be assembled at the space station from components delivered by the shuttle. NASA expects to have the space station operating in the 1990s.

Both manned ships and unmanned cargo ships could be used in a voyage to Mars. Manned ships, which must support a crew over a nine-month flight between the two planets, will require heavy, complicated, and expensive habitation and life-support equipment. Everything not absolutely necessary for the crew on the Mars transit could be sent ahead on unmanned cargo vehicles, which can be relatively simple and inexpensive.

The choice of a propulsion system will affect the designs of both manned and unmanned vehicles. Conventional rockets launched from the surface of the Earth use chemical propellants, frequently combining liquid oxygen and liquid hydrogen to produce a powerful thrust. This is the only propulsion technology that has been adequately tested in space that has enough thrust to overcome gravity at Earth's surface. However, it consumes large amounts of fuel, posing problems for a long interplanetary flight. The fuel for the return trip must be carried on board, which further increases the weight of the vehicle and raises its fuel requirements. For each ton of fuel needed for the return trip, 5 to 10 tons of fuel are needed to boost this extra propellant to Mars.

More efficient propulsion systems would reduce the fuel costs of exploring Mars. The solar sail is an attractive possibility for propelling the unmanned cargo vehicles, which can travel slowly. Solar sails, first proposed by Russian researchers Konstantin Tsiolkovsky and Fridrikh Tsander in the early 1920s, use no rocket engines and expend no fuel. Instead, photons radiated from the sun strike a sheet of shiny material such as aluminized plastic film to provide the thrust. The sail must be one to two kilometers on a side to gather enough sunlight to create reasonable propulsive force. The World Space Foundation (WSF), a private research and development organization in Pasadena, Calif., has designed a solar-sail-propelled vehicle and plans to launch a prototype by 1987.

Robert Stachle, an aerospace engineer with NASA's Jet Propulsion Laboratory and president of WSF, has outlined a mission to Mars using a fleet of remote-controlled solar-sail cargo vehicles. Fifty to sixty shuttle payloads would be needed for the mission, of which about twenty would be used to construct a fleet of two-kilometer-square sails. These could tow over 400 tons of equipment and supplies—enough to support an initial Mars landing crew of eight—from a staging area in low-Earth orbit to Mars. The trip to Mars would take almost four years, but the solar-sail vehicles could also serve as a continuous ferry for samples and supplies between Earth and Mars.

Another promising technology for cargo ships is electric propulsion, or "ion drive." This technology uses electric power to transform a propellant into charged particles, which are then accelerated by an electric field and expelled at high velocities. The thrust of the electric-propulsion engine depends on the rate at which the ions are expelled, which in turn depends on the size of the electric power supply. Currently available power supplies provide an engine thrust that is low compared with chemical propulsion. However, an ion-drive engine consumes only one-tenth the fuel of a chemical engine to produce the same propulsive force.

Born in the mid-1950s, the concept of electric propulsion has inspired small-scale research and development work for decades. In 1970, NASA put a satellite with ion thrusters into orbit and test-fired them over a ten-year period. Early electric propulsion systems used nuclear reactors to provide the power, but the trend since

the mid-1960s has been toward using banks of solar panels. Solar-powered electric propulsion (SEPS) may well be the optimal system for unmanned Mars vehicles. Propellants for solar electric propulsion are either metallic conductors such as mercury or ionizable fluids such as argon gas. Argon makes up 1.6 percent of the martian atmosphere and has been tested for SEPS use at NASA's Lewis Research Center in Cincinatti. If a space vehicle could refuel for a return trip with argon derived from Mars' atmosphere, the weight that must be launched from Earth, and hence mission costs, would be reduced.

The solar panels from a SEPS engine could also be used to generate electricity when a spacecraft is parked in Mars orbit. As first proposed by Peter Glaser of Arthur D. Little, Inc., in Cambridge, Mass., this electrical energy could conceivably be converted to laser or microwave radiation and beamed to receiver stations on Mars. Such a process may be better suited to providing power on Mars than on Earth, because the thin atmosphere will not scatter the beams and there is clearly less potential for biological harm.

The disadvantage of solar-sail and electric propulsion systems is that neither has enough thrust for a planetary takeoff. However, a hybrid system could use chemical propulsion to escape gravity and solar sails or electric propulsion for interplanetary flight. Fuel requirements for the hybrid system would be several times lower than for chemical systems alone.

To minimize the crew's exposure to the potentially harmful effects of space flight, the manned spaceship must travel at speeds faster than are possible using solar sails or electric propulsion. Therefore, conventional chemical propulsion such as that used on the space shuttle is the best option in the near future for manned vehicles.

Once the manned spaceship arrives at Mars, fuel could be saved by "aerobraking"—using the upper layers of the planet's atmosphere to slow the vehicle's passage. Aerocapture occurs when the craft sheds enough of its initial velocity to enter an orbit around the planet. The conventional breaking method, in which forward-facing rockets slow the spacecraft, consumes a great deal of fuel. A vehicle using the aerocapture technique could potentially put twice as much payload weight into Mars parking orbit for the same launch cost as could a vehicle using rocket engines alone. A mission using both aerocapture and solar-sail or

"The Moon Is Not the Ultimate Goal"

It's been said that if all the spaceships ever proposed for traveling to Mars were actually built and then laid end to end, the result might reach halfway to the intended destination. That's stretching things a bit, but many proposals have been advanced for traveling to the Red Planet.

Wernher von Braun, who pioneered the development of rockets that eventually propelled astronauts to the moon, made the first detailed analysis of a Mars mission in 1952. His engineering blueprint, published as the *Mars Project*, called for a shuttle-like vehicle that would ferry huge amounts of equipment from Earth to an orbit in space, where it would be assembled into ten spacecraft. The ships, each carrying a crew of seven, would then travel in convoy, and the landing party would spend 400 days on the martian surface.

In the early sixties, when the unswerving focus of the Apollo program seeded boundless excitement for space exploration, the idea of a manned mission to Mars received serious attention. In 1963, the American Astronautical Society sponsored what was called the first planning symposium, which drew 800 scientists and engineers.

The next year von Braun, who was then director of the Marshall Spaceflight Center in Huntsville, Ala., organized a similar conference. "Although the nation is firmly dedicated to achieving a manned lunar landing in this decade, landing on the moon is not the ultimate goal," he declared. "Man will travel beyond the moon to explore the solar system. When, I do not know. But it will take all the disciplines of technology and management to push the frontiers of space into the backyards of the planets."

By the time of the 1969 Apollo moon landing, space engineers had developed a "NASA standard man-to-Mars mission," writes James Oberg, an engineer at the Johnson Space Center in Houston, in *Mission to Mars*. "For many space workers, the moon was only a detour, a temporary distraction from the serious business of getting to Mars."

However, politics intruded. The expensive war in Vietnam aroused the anger of Congress, and President Nixon viewed a costly space program as a potential liability. NASA saw its budget clipped and its horizons foreshortened.

Officially, any plans for a manned mission to Mars retreated to the back of the file drawer. But unofficially, individuals continued to develop plans in private, biding time until the political winds freshened in their direction.

In the spring of 1981, this underground of Mars enthusiasts emerged at a conference organized by Carol Stoker, Christopher McKay, and a number of other students at the University of Colorado. About one hundred people met for three days, drawing up ideas for everything from propulsion systems to martian farms. The participants also identified many of the critical problems and outlined areas for further research.

"Among all these plans are bound to be ideas useful when the time comes again to officially plan a NASA man-to-Mars expedition," writes Oberg. "If not, there is little doubt that their plans have been carefully translated into Russian."

Mars enthusiasts are continuing their efforts today. The Mars Institute, recently started by the Planetary Society, will sponsor courses at various universities for studying a manned Mars mission. And a Second Case for Mars conference will meet in Boulder in July 1984.—*Jeanne McDermott* □

SEPS cargo vehicles would reduce fuel requirements and help offset the development costs of these new propulsion systems, particularly if there is a long-term settlement on Mars.

Over the Long Haul

The trip to Mars will last longer than any manned mission ever launched. Each interplanetary haul will take nine months, and the crew will have to stay a minimum of one year on Mars to take advantage of the optimal alignment of Mars and Earth for traveling. Thus, the shortest trip will last over two and a half years, much of which the crew will spend in the spaceship.

During such a long voyage, the crew must feel comfortable. Unfortunately, the larger the spaceship, the more expensive it is to launch. But Thomas C. Taylor, a consulting engineer from Taylor Associates of Los Angeles, has proposed a low-cost way to build the crew's quarters. While working on the oil pipeline in Point Barrow, Alaska, where packing crates for oil-rig supplies were used as dwellings and clubhouses, Taylor recognized the value of recycling materials. He suggests saving and retrofitting the shuttle's external fuel tank for life-support facilities for a manned ship. This tank is lightweight and extremely roomy; in fact, it is five times larger than *Skylab*, which housed three astronauts for 84 days. Best of all, the tank would already be in space—it now drops off from the shuttle when its fuel is expended and burns up in the atmosphere. But if the tank were boosted into a slightly higher stable orbit, it could be retrofitted for Mars transit at the space station.

Several retrofitted tanks could be joined together to accommodate larger crews. Furthermore, if crews found the deleterious effects of microgravity too severe, several tanks could be connected in a donut-shaped configuration and rotated to produce artificial gravity.

Life Support

Meeting the human requirements of long interplanetary flights is one of the most difficult challenges. Astronauts must have adequate diets and avoid overexposure to toxic substances and radiation. They must adapt to space sickness and the lack of gravity. They must deal with the psychological stress associated with isolation and confinement. And when they land, they must readapt to a high-gravity environment.

Each crew member will need four pounds of water, three pounds of food, and two pounds of oxygen a day. Life-support systems can be "open," so that all materials are provided fresh and used only once, or "closed," so that waste products are processed and recycled. The open system is simple and reliable but its cost climbs as the trip lengthens. The closed system may require heavy, complex, and fail-safe recycling equipment but may weigh less for long missions.

Current technology for closed and semiclosed life-support systems is inadequate for long stays in space, but both are receiving renewed attention because they will be essential for a space station. Partial recycling of food, water, and waste will be easier to achieve than total recycling. Revitalizing the air, which includes removing carbon dioxide, is essential, and can be accomplished with the technology already on the shuttle. The Soviets recycle 50 percent of a spaceship's water simply by recovering exhaled water from cabin humidity. Recovering water from wash water and urine, although difficult, can be done using a complex procedure of distillation and filtration. Recycling solid waste to grow food is the most expensive and difficult process of all and will probably not be cost effective.

Space takes a toll on human health—but just how serious a toll remains to be seen. In microgravity, the heart and other muscles atrophy. Although exercise can help maintain muscle tone, designing a program that adequately uses all the muscles is difficult. The Soviets, who have considerable experience with weightlessness, combat the problem with elastic space suits that force the muscles to work continuously.

Perhaps a more insidious problem is the loss of calcium from weight-bearing bones. Physicians are not certain why this occurs, but they have noticed that patients bedridden for months in a body cast suffer the same loss. A 10 percent loss of bone calcium is considered serious, and astronauts may lose up to half a percent a month. Some drug therapies have been suggested to halt or at least slow this condition, but they remain untested. Fortunately, loss of calcium stops and reverses on return to a high-gravity environment. However, a crew could be highly susceptible to bone fracture for a period after landing on Mars.

Another major health concern is the high amount of radiation astronauts will encounter throughout the flight to Mars. Astronauts will be exposed to at least 40 rems per year of harmful background radiation from the sun and other stars. In addition, solar flares deliver upward of 60 rems of radiation in an average year and several times that amount in a bad year. Federal health standards allow a total ex-

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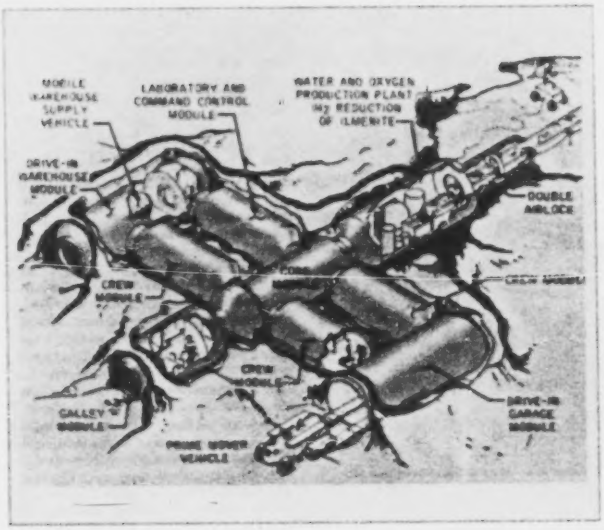

A permanent Mars base must be near water, fuels, minerals, and building resources, and be situated to allow communication with Earth. The site must also be close to scientifically interesting regions. An early NASA scenario thought a permanent base might look like this (left). Before Mars is settled, its surface should be mapped for water and minerals using NASA's proposed geoscience/ climatology orbiter.

posure of 300 rems over a 20-year career. For protection against short, fierce solar flares, a Mars ship will need a "storm cellar" designed to place as much mass as possible between the crew and the sun. The radiation hazard might favor selecting older astronauts, or at least those past childbearing age.

To maintain astronauts' mental health, Dr. B.J. Bluth, a space psychologist at California State University in Northridge, suggests sending a minimum of seven crew members on any mission. The crew should be composed of an odd number of personnel to prevent deadlocks in command and ensure democratic decision making. It should include both men and women of different professions, backgrounds, and personalities who are taught to withstand the demands and stresses of the mission, and to work together equitably and develop a chain of command and protocol. While the Soviet space program has had considerable success in teaching astronauts how to manage stress, this type of training has been lacking in the U.S. space program.

Settling In

When manned ships first arrive on Mars, the crew's first priority will be to establish a permanent base as self-sufficient as practical. For safety reasons, the pioneering crew should go to Mars with enough food and supplies to last the entire mission, but later crews can rely on locally produced supplies. The martian water supply will have to be tapped immediately. Thomas Meyer of the Boulder Center for Science and Policy has suggested using conventional air compressors to obtain water. At typical nighttime temperatures, martian air is at nearly 100 percent relative humidity. If it is compressed while keeping the temperature constant, water will condense. Meyer and colleagues estimate that extracting each kilogram of water will require up to 400 kilowatt-hours of electricity to drive the compressors. Although supplying that amount of energy may be difficult, the atmospheric supply of water is inexhaustible because water is replenished through evaporation at the poles.

Water could also be extracted by heating martian soil. Dr. Benton Clark of Martin Marietta Co. in Denver estimates that 10 to 100 metric tons of water could be extracted per month, even from dry martian soil, using a 50-kilowatt heat source. Finally, the ice reservoirs at the poles or the permafrost in the lower latitudes could be mined with excavating or blasting equipment.

An air supply will be needed inside dwellings and workplaces. Breathable air must have enough oxygen pressure and an inert buffer gas that inhibits combustion. Carbon dioxide, the primary constituent of martian air, will liquify if the air is compressed and can be processed to obtain oxygen. Nitrogen and argon, the other major constituents of the martian atmosphere, could be used as buffer gasses after the carbon dioxide is removed. Since the buffer gas is not directly consumed, it would not have to be continuously resupplied.

Solar panels could provide power for the base, either from the orbiting SEPS spacecraft or on the ground. A small nuclear fission reactor is also a realistic power option. Although the equipment for both systems must be carried to Mars, neither requires frequent resupply.

Fuels for the return trip could possibly be made on Mars or its moons. An argon-propelled SEPS ship could be refueled using argon from martian air. The chemical propellants burned during takeoff and landing could also be resupplied if enough water is available. Solar or nuclear-generated electricity could be used to split the water into oxygen and hydrogen for the rocket fuel. Hydrogen could also be reacted with carbon dioxide to produce methane, which can be used as fuel.

Martian soil could be the basis for greenhouse agriculture. Although the soil contains sodium and magnesium sulfates as well as sodium chloride, these salts can be diluted with sufficient washing. Adding organic material from human waste will improve the soil's fertility. And the nitrogen in martian air can be reacted with hydrogen to produce an ammonia-based fertilizer.

Standard food crops could be grown in above-ground greenhouses. Penelope Boston, a biologist at the University of Colorado, has shown that plants can grow at low atmospheric pressure. She suggests using plastic tents that maintain an air pressure 10 percent of that on Earth. Greenhouse air could be produced by

manipulating the gas composition of martian air for optimal plant growth. Oxygen, the by-product of plant photosynthesis, could possibly be filtered from the greenhouses for use in human habitats.

Construction and manufacturing materials can also be made from martian soil. With the addition of water, soil can be formed into an adobelike brick for use in building houses. Dr. Benton Clark of Martin Marietta Co. has proposed processes to create a number of other building materials. For example, magnesium is a machinable metal that can be extracted from martian soil. Soil can be converted to glass by heating it to a high temperature. And a wide variety of cements can be easily manufactured using calcium, magnesium, and sulfur compounds.

Living quarters and seed-storage areas are best kept underground to shield people and seeds from radiation damage. Underground habitats also provide natural insulation against the temperature extremes of the martian environment. In addition, they could be easily sealed to enclose a breathable atmosphere.

Because of the low atmospheric pressure and temperature extremes on Mars, humans must wear pressurized and thermally insulated suits above ground. The suits must allow a range of at least 5 kilometers and be flexible enough to perform complex tasks. Life-support requirements would limit a manned rover, needed for exploring and expanding the base, to a range of about 50 kilometers.

The Mars base will ultimately be devoted to science after it is well established. Exploration and research will require remote-controlled vehicles able to travel at least 1,000 kilometers and return samples to the base. Such vehicles would not require the sophisticated artificial intelligence and mechanical design of a self-sufficient robotic rover, as the scientist operating the vehicle could decide how best to avoid an obstacle or which samples to retrieve. Several types of remote-controlled or robotic rover vehicles have already been proposed, including the Mars airplane—a glider designed by Victor Clarke of NASA's Jet Propulsion Laboratory and colleagues for the low atmospheric pressure of Mars. With a 21-meter wingspan, the glider can range up to 10,000 kilometers, carry and land instrument packages, collect samples, and conduct aerial surveys.

What Will It Cost?

Probably the most important factor in the decision to go to Mars is the mission's cost. The high cost of landing on the moon profoundly influenced the public's and politicians' attitude toward space exploration. Legislators and even NASA administrators often assume that new programs will cost much more than Apollo, disregarding the advances that have occurred since the Apollo era.

A manned mission to Mars first appears to be extremely ambitious and therefore prohibitively expensive. However, a detailed study by Humbold Mandell, Jr., a cost analyst at NASA's Johnson Space Center in Houston, indicates that, as mentioned, a single manned mission to Mars could be staged for one-half to one-third the cost of the Apollo program—or just over $20 billion compared with about $60 billion (in 1981 dollars). The total cost of a Mars landing would represent less than 1 percent of the estimated gross national product for 1990, while the total cost of Apollo was 2.8 percent of the average GNP during a single year during that time. Today's military budget annually is over 10 percent of the GNP.

In his estimate, Mandell assumes that the Mars mission would have a short, Apollo-style landing and use the space shuttle and today's space hardware. Costs would be lower than those of the Apollo program because much of the necessary technology already exists, and many development costs could be shared with other programs such as the space station.

A program that established a continued presence on the martian surface would cost more in the long-term. However, while some observers may suggest limiting the exploration of Mars to one or a few Apollo-style missions, the benefits of these missions diminish with their scope. Small-scale missions would fail to adequately study or develop the planet's economic and strategic potential. Considering the unique economic, social, and political implications of a martian settlement, cost should not be a deterrent.

Public interest in and support for exploring space are unquestionably reawakening. However, the motives behind this resurgence are very different from the international competition that first sent us to the moon. A program to settle Mars would provide the focus to meet the new challenge. □

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Mariner Mark II and the Exploration of the Solar System

Marcia Neugebauer

Summary. Mariner Mark II is a concept for the next generation of deep-space missions. The project would provide limited, focused sets of Voyager- and Galileo-quality planetary observations at a fraction of the cost of the Voyager and Galileo projects. This article discusses Mariner Mark II's cost goals, scientific objectives, and mission requirements. Strategies for limiting costs include the use of a reconfigurable spacecraft, a multimission ground-support system, and selected new technologies.

As planetary spacecraft technology evolved from the relatively simple Mariner flybys of Venus and Mars to the planned Galileo mission to Jupiter, the emphasis has always been on improved performance. Each mission has returned greater amounts of more sophisticated data than its predecessors. Today, because of severe economic constraints, the outlook is different. The Solar System Exploration Committee (SSEC) of the National Aeronautics and Space Administration (NASA) has been developing a strategy for future planetary research based on a lower cost per mission rather than higher performance.

The SSEC is considering both near-Earth and deep-space missions. Many of the near-Earth missions (to the moon, Venus, Mars, and Earth-approaching asteroids) may be accomplished at relatively low cost with the present generation of Earth-orbiting spacecraft. Several aerospace companies are analyzing methods for adapting spacecraft such as Tiros, Atmospheric Explorer, Fltsatcom (fleet satellite communications), and GOES (geostationary orbital earth satellites) to study Martian geochemistry, climate, and atmosphere, to map the geochemical properties of the moon, or to explore a near-Earth asteroid.

Deep-space missions to comets, main-belt asteroids, and the outer planets require specially designed power, telecommunications, and thermal control systems that operate over a large range of distances from Earth. Under the direction of NASA and SSEC, the Jet Propulsion Laboratory is studying the development of a workhorse called Mariner Mark II for the next generation of deep-space planetary missions. Mariner Mark II is being designed to perform limited sets of Voyager- or Galileo-quality measurements in deep space or to deliver Galileo-type atmospheric probes to the outer planets at a fraction of the cost per mission of the Voyager and Galileo projects.

Tens of thousands of striking pictures of the Jupiter and Saturn systems were sent back by Voyager (*1*). These pictures were obtained by a black and white television camera with a resolution of 800 by 800 picture elements (allowing finer detail than possible with the 520 lines of an ordinary television). Color photography and spectral information were obtained by sequential use of a set of different filters. For Galileo, the Vidicon television tube used on Voyager will be replaced by solid-state detectors called charge-coupled devices (CCD's) to achieve wider spectral response, greater photometric accuracy, and increased sensitivity. The term Voyager- or Galileo-quality also implies the following: (i) the capability to map certain physical properties and the chemical composition of individual features on the surfaces of solid bodies; (ii) the capability to determine the structure and dynamics of planetary atmospheres together with the abundances of many specific atoms and molecules by remote sensing at ultraviolet, visible, and infrared wavelengths; (iii) the capability to send an instrumented probe into a planetary atmosphere to sense the frequency and intensity of lightning bursts and to directly sample pressure and temperature structure, composition (both elemental and isotopic), and the size and shape of aerosols; (iv) the capability to measure the composition and distribution of energetic charged particles and low-energy plasmas in planetary ionospheres and magnetospheres, together with the magnetic field and plasma waves that interact with the charged particles; and (v) the capability to determine the distribution and some of the physical and chemical properties of dust grains by observing the details of how they absorb and reflect sunlight and by direct measurements of a few individual grains.

Mariner Mark II starts with these existing capabilities and uses new technology principally to reduce mission costs rather than to improve spacecraft performance. The spacecraft would be reconfigurable at low cost to meet the different requirements of different missions, while a multimission ground system would be able to support any of the spacecraft without reconfiguration.

The cost history of U.S. planetary and interplanetary projects is shown in Fig. 1 in terms of both dollars spent and an equivalent 1982 cost that accounts for inflation. Twin spacecraft, such as Voyagers 1 and 2, are counted as a single project. A much lower than average cost characterizes missions that were based on the designs of earlier missions. These

Marcia Neugebauer is a senior research scientist and acting manager of the Mariner Mark II Development Flight Project at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91109.

include Mariners 1 and 2, derived from earlier Ranger spacecraft; Mariner 5, derived from Mariners 3 and 4; and Mariners 8, 9, and 10, derived from Mariners 6 and 7. The goal of the Mariner Mark II project is to develop the capability for a series of planetary missions in the 1990's with a 1982-equivalent cost between $150 million and $300 million per mission. For a sequence of four or five missions in 10 years the average expenditure per year is planned to be limited to approximately $100 million. The data in Fig. 1 suggest that these goals are probably attainable if a high level of inheritance can be achieved across missions.

Ironically, one reality that brings the Mariner Mark II goals within reach is the present time gap in funding planetary exploration. The Galileo project, which was approved and started in 1977, is the only planetary mission under development in the United States. The gap between the start of Galileo and the start of the next deep-space project is being used to examine the requirements of this next generation and to determine the most cost-effective way of meeting them.

The study of comets is one of the highest priorities of future planetary research (*2*). Comets are the only obtainable source of the primitive material from which the solar system evolved. They are believed to contain a record of the physical and chemical conditions of the interstellar medium and the primordial solar nebula. Furthermore, comets may have contributed appreciable amounts of volatile material to the present atmospheres of the terrestrial planets (*3*); it has also been suggested that cometary material was important to the evolution of life on Earth (*4*).

The 1986 European, Soviet, and Japanese flybys of Halley's comet will address many important questions about the composition of the gas and dust that form the cometary halo and tails visible from Earth. The missions are expected to verify Whipple's (*5*) hypothesis that cometary nuclei are small (diameter, 0.1 to 100 kilometers) "dirty snowballs" that vaporize and become very active when they come close to the sun.

A thorough investigation of a comet requires a much longer period of observation than that provided by a flyby mission. A rendezvous mission is required so that the comet can be watched for a period of months as it approaches and retreats from the sun. With very small propulsion maneuvers, a spacecraft in rendezvous with a comet can move around the nucleus and view it from different distances and directions. The physical and chemical nature of the nucleus can be determined with Galileo-quality imaging and infrared mapping systems as well as with x-ray or gamma-ray spectrometers. Direct measurements can also be made of the gas and dust in the comet's atmosphere.

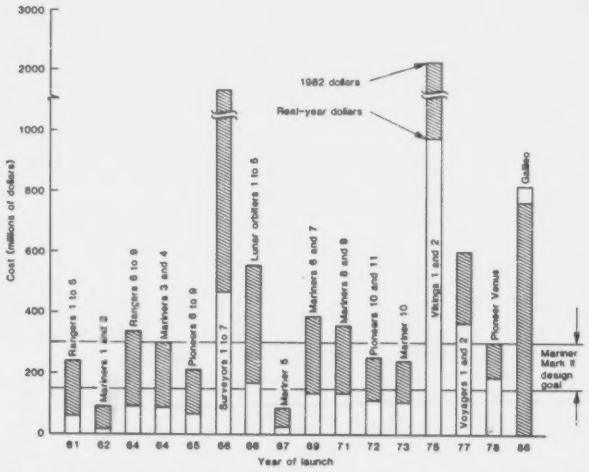

Fig. 1. Deep-space mission costs. The figures reflect current NASA bookkeeping practice in that they include all costs of building and operating the spacecraft and analyzing the returned data, but not the cost of either the launch vehicle or the operation of the deep-space data acquisition facilities. Data for Pioneers 10 and 11, Pioneer Venus, and Voyager are through the end of fiscal year 1981.

The choice of targets for a comet rendezvous is limited by available and planned launch vehicles to short-period comets in low-inclination orbits. Comets Honda-Mrkos-Pajdusakova and Tempel 2 are the two best candidates for the 1990's.

While observations with a rendezvous spacecraft can enormously increase our knowledge of comets, the ultimate step would be to collect and return a portion of a comet's nucleus for detailed analyses in sophisticated ground-based laboratories. The propulsion capability required to carry out such an ambitious task is not available; it is possible, however, to sweep up cometary gas and dust with a spacecraft that passes through a comet's atmosphere at high velocity and to return that sample to Earth for analysis. The spacecraft would necessarily move through the comet at such high speed that information about the physical and chemical states of the dust and gas would be lost because of vaporization and plasmatization caused by the impact. But elemental and isotopic analyses of the collision debris would provide new information on the generic relation of the comet to other solar system bodies and to interstellar matter. A high degree of synergism can be gained by studying the same comet with simultaneous rendezvous and sample-return missions.

Like comets, asteroids are relevant to a wide variety of questions about the origin and evolution of the solar system. Since asteroids are relatively small bodies, it is thought that radiogenic heating and other endogenic processes have had much less effect on them than on larger bodies such as the Earth and moon. An asteroid's structure and morphology and some features of its mineralogy and elemental composition should indicate its environment and state during and shortly after its creation. Earth-based observations indicate that there are many different types of asteroids. For spacecraft missions there are two sets of objects to be considered: main-belt asteroids between the orbits of Mars and Jupiter and Earth-approaching asteroids on temporary, unstable orbits with typical lifetimes of a few tens of millions of years. The source of Earth-approaching asteroids is not known; some or all of them may be exhausted comets. There is also an apparent systematic variation of composition with position in the asteroid

belt, which is probably a relic of radial gradients in the condensing solar nebula. The diversity of asteroids requires that more than one type be studied at close range.

The Mariner Mark II study addresses the possibility of performing a rendezvous with one or possibly two main-belt asteroids and flying by several others, all with a single spacecraft. Main-belt asteroid rendezvous missions could be achieved with Galileo-era launch vehicles by designing a trajectory that takes the spacecraft close enough to Mars to obtain a gravitational boost in orbital energy from that planet. Additional energy could be gained by proper timing of a rocket firing during the Mars encounter. Such a maneuver would allow the spacecraft to obtain an asteroid-like orbit about the sun. Once the spacecraft reached the asteroid belt there would be a very large number of target bodies to choose from.

Future planetary exploration will also focus on the outer planets. Again, the emphasis will be on learning more about the origin and evolution of the solar system. Systematic differences between Jupiter, Saturn, Uranus, and Neptune reflect radial variations in the physical and chemical properties of the primordial solar nebula. The outer planets have a wide variety of satellite and ring systems; understanding the dynamics of these systems is a prerequisite to understanding the agglomeration and accretion of the planets and their satellites. Other than the Earth, Saturn's moon Titan is the only solar system body with a nitrogen-rich atmosphere. Titan has been likened to the Earth early in its development. Large amounts of methane are also present, which raises the possibility of organic chemical reactions, possibly similar to those on the prebiotic Earth. It is possible that methane is near saturation in Titan's lower atmosphere and that liquid methane is present on the surface.

The Pioneer and Voyager missions provided an initial reconnaissance of Saturn and its rings and satellites, and Voyager is expected to do the same at Uranus in 1986. To achieve the next level of understanding, Mariner Mark II could deliver entry probes or provide a Saturn orbiter. Because Titan's atmosphere is opaque at visible wavelengths, Voyager could learn only a little about the composition and structure of its atmosphere and nothing about the physical nature of its surface. New data could be obtained by sending an instrumented probe into Titan's atmosphere and by observing Titan at infrared and radio wavelengths. Radar and infrared mapping could be carried out from the spacecraft used to deliver the atmospheric probe and to relay its data to Earth. More complete mapping could be conducted from a spacecraft in orbit around Saturn.

A Saturn orbiter would, of course, have other objectives in addition to studying Titan, and a variety of different Saturn orbits can be obtained by repeated close flybys of Titan. The 3-year scenario shown in Fig. 2 features 22 encounters with Titan plus close (< 2500 km) encounters of the satellites Dione, Rhea, Hyperion, and Iapetus. The key element provided by a Saturn orbiter is the ability to study satellite surfaces and Saturn's atmosphere as well as ring and magnetospheric phenomena over an extended period of time and at a variety of geometries and conditions.

As with Titan, new data about the atmospheres of each of the outer planets can be obtained with entry probes. Instruments like those carried on the Galileo Jupiter probe would be able to measure the molecular and isotopic compositions of the atmospheres of Saturn, Uranus, and Neptune as functions of depth down to pressure levels of 10 to 20 bars.

The Mariner Mark II is principally designed to study minor bodies and the outer solar system. But its capabilities could be applied to study the terrestrial planets as well. The option that has been studied in greatest detail is a Mars orbiter suited for geochemical and climatic studies. The reason for studying Mars is not so much to increase our knowledge of how the solar system evolved but rather to learn more about how it is evolving and, in particular, to understand what may be in store for the Earth. An understanding of past and present processes on Mars requires mapping of the chemical and mineralogical characteristics of the surface and determining the sources, sinks, abundances, and circulations of volatiles and dust in the atmosphere.

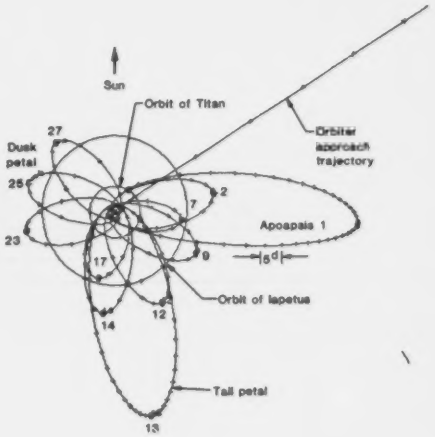

Fig. 2. Example of one possible 3-year tour of the Saturn system (6). For clarity, only ten of the 26 orbital loops have been drawn.

Mission Characteristics and Requirements

The space shuttle would be used as a launching platform for all the Mariner Mark II missions. The boost out of low-Earth orbit would be provided by the Air Force two-stage Inertial Upper Stage (IUS) or a higher energy Centaur rocket using liquid hydrogen and oxygen as fuels (Table 1). Funds for the development of a shuttle-compatible Centaur were approved in July. Some proposed missions require still another stage of propulsion, which could be provided by a Star-48 solid rocket motor after the IUS or Centaur has burned out and been jettisoned.

Most of the candidate missions have substantial requirements for postlaunch propulsion for orbit insertion, for matching the velocity vector of a rendezvous target, or for interplanetary maneuvers required to reach the target. Many of the candidate missions are also of long duration, ranging up to 11 years. This fact has a significant impact on the reliability

required of the spacecraft and on the level of redundancy in the design.

Many of the missions will require precise navigation. The Titan mission must rely on optical navigation for acceptably accurate delivery of its atmospheric probe. The ephemerides of the comet and asteroid targets are even less well known because of the relative scarcity of observations. Furthermore, as gas escapes from the warmer side of a comet, conservation of momentum results in an acceleration of the comet body in the opposite direction. The comet's orbit can be substantially altered by such jet action. Optical navigation requires imaging of the comet or asteroid against a background of stars of magnitude 9 or 10. This requirement can be easily met with the Galileo CCD camera sensor on a three-axis–stabilized platform.

Voyager- or Galileo-quality imaging will also be of highest scientific priority for the comet and asteroid rendezvous and the Saturn orbiter missions. Remote-sensing instruments also benefit greatly if the spacecraft is able to keep them trained on the target. Measurements that require long integration times are made possible through the use of a platform with active pointing control. Over 80 percent of the surface of Titan can be mapped with a radar antenna mounted on a movable scan platform such that one hemisphere is viewed on approach and the other as the spacecraft leaves Titan. Thus, navigation and remote sensing both call for a stabilized rather than a spinning spacecraft.

The imaging systems, multispectral mapping instruments, and radar for the Titan mission will all produce large amounts of data. Model profiles suggest that, even with the data compression techniques now coming into use, telecommunication rates will be on the order of 10,000 to 30,000 bits per second. The data links must be maintained over distances as great as 10.5 astronomical units (AU) for Saturn. The distances to Uranus and Neptune are even greater, but the smaller amount of data acquired by flyby and probe missions can be stored and then transmitted at a lower rate.

Other requirements of the Mariner Mark II spacecraft include the following: (i) it must operate at distances from the sun ranging from 1 to 30 AU, if a Neptune mission is included in the set; (ii) it must be capable of carrying and releasing an atmospheric probe or a capsule to return material to Earth; (iii) for missions with high-resolution imaging, it must have a pointing accuracy of about 2 milliradians; and (iv) it must support and be compatible with the scientific instruments to be flown.

The basic requirements of the Mariner Mark II spacecraft are summarized in Table 2. Some of these requirements would have to be extended, at additional cost, to carry out certain missions. These extensions include an on-board propulsion capability between 3 and 4 km/sec for some multiple main-belt asteroid tours, longer durations and larger distances for the Uranus and Neptune missions, and a closer approach (0.34 AU) to the sun if Encke were chosen as the target for a comet rendezvous mission.

Implementation

How is it possible to meet the requirements listed in Table 2 and the Mariner Mark II cost goals at the same time? The strategy, which is based on the assumption that Mariner Mark II will be used for a series of four or five missions over a 10-year period, has four components: (i) objectives and operations must be kept as simple as possible; (ii) the system must be easily reconfigured from one mission to the next; (iii) requirements must be set to provide more conservative design margins than in the past; and (iv) new technology should be used to reduce costs rather than to achieve performance beyond the minimum mission needs.

Simplicity. One way to keep the missions simple is to restrict the scientific objectives of each mission. Figure 1 shows that Viking and Galileo are two of the more expensive recent projects. Both missions have diverse rather than

Table 1. Summary of candidate Mariner Mark II missions.

Mission	Launch opportunities	Launch mode*	Mission duration (years)	Time spent at target	Post-launch ΔV (km/sec)
Comet rendezvous	1989, 1990,† 1991, 1992, 1994, 1995, 1996	Centaur	5.5	6 months	2.2 to 2.9
Comet sample return	1989, 1990, 1992, 1994, 1999	IUS	2 to 3	1 day	0.2 to 1
Main-belt asteroid flybys and rendezvous	Every 26 months	IUS, S48, and MGA or Centaur and MGA	2 to 7	6 months	3 to 4
Saturn orbiter	Every year (1998†)	Centaur and JGA	7 to 11	≤ 3 years	2.0 to 2.3
Titan or Saturn flyby and probe	Every year	Centaur and S48	3.5	1 day	0.2
Uranus flyby and probe	1992, 1994†	Centaur, S48, and JGA	5.5 to 8‡	1 day	0.2
Neptune flyby and probe	1992, 1994†	Centaur, S48, and JGA	8 to 10‡	1 day	0.2
Mars orbiter	Every 26 months	IUS	2.8 to 3.2	2.2 years	2.2 to 2.7

*The spacecraft would all be launched from the space shuttle by either a two-stage IUS propulsion system or by the higher performance Centaur. A notation of S48 indicates that an additional stage of propulsion equivalent to a Star-48 solid rocket motor is also required. Missions in which momentum is gained by flying by Mars or Jupiter are indicated by MGA or JGA, respectively. †Best opportunity. ‡The longer flight times would be required to avoid a close flyby of Jupiter, which requires special radiation hardening of spacecraft.

focused objectives. The Viking project had two orbiters for global mapping plus two landers that probed the atmosphere and then made detailed observations of the two landing sites. The Galileo project includes an atmospheric probe and an orbiter. The orbiter, in turn, has a three-axis–stabilized section to optimize remote sensing of Jupiter and its moons and a spinning section to optimize magnetospheric measurements. For Mariner Mark II, a Saturn probe, Titan probe, and Saturn orbiter would be three separate, focused missions. Furthermore, the Saturn orbiter would not have a spinning section. Adequate magnetospheric particle measurements could still be made with sets of wide-angle sensors. The disadvantage of a fixed orientation for magnetospheric measurements is generally outweighed by its advantage for remote sensing.

The ground-support system must also be as simple and as inexpensive as possible. Two keys to simplification of the ground system are automation and autonomy of the spacecraft—which, of course, increase the spacecraft's cost. The Mariner Mark II missions are generally of such long duration that the net payoff for on-board automation would be high. The spacecraft must be able to care for itself for many days without commands from the ground. During the long cruise toward the target, a radio signal would continuously indicate the state of health of the spacecraft. This signal would be monitored once or twice a week and an alarm system could be automatically activated if anything were amiss.

Once at the target, the sequencing of spacecraft operations must be as simple as possible, with a minimum number of modes or states of activity. With its large number of satellite encounters, the Saturn orbiter tour (Fig. 2) would be especially vulnerable to an escalation of costs associated with spacecraft and instrument sequencing. The inclusion of an automatic target tracker and "smart," self-adjusting instruments might be cost-effective for such a mission.

Each instrument must also operate as independently as possible. Power and data handling margins would be sufficiently large to allow an instrument to change its mode of operation, either automatically or by ground command, without prior coordination, scheduling, and simulation of the effect of the change on the spacecraft and the other instruments and without verification of proper receipt of commands.

Reconfigurability. A basic requirement of the Mariner Mark II concept is that the spacecraft be reconfigurable at low cost from one mission to the next. A high degree of inheritance from mission to mission must be planned from the start. A modular spacecraft configuration is being developed to satisfy this requirement over the range of missions listed in Table 1 (Fig. 3). The baseline attitude control mode is a three-axis, celestially fixed attitude with the Earth and a bright star as references. A central module houses all of the spacecraft electronics and electromechanical and electrochemical assemblies that do not require external mounting.

Table 2. Mariner Mark II spacecraft requirements.

Requirement	Possible extension
Shuttle IUS or Centaur launch	
Postlaunch propulsion, ≤ 3 km/sec	4 km/sec
Mission duration, ≤ 8 years	11 years
Communication distance, ≤ 11 AU	30 AU
Solar distance, 1 to 10 AU	0.34 to 30 AU
Optical navigation	
Attitude control, three-axis–stabilized with 2-mrad pointing accuracy	
Data rate, 10 to 30 kilobits per second	
On-board data storage	
Probe delivery or capsule capacity	
Support of and compatibility with instruments selected for flight	

Several different modules are attached to the central module. The interfaces between each of the external modules and the central module will be as mechanically, electrically, thermally, and logically standardized as possible across the mission set. The design of these interfaces thus requires careful consideration of each of the missions as well as of the possible introduction of new technology.

The radio-frequency module includes a fixed high-gain antenna together with its antenna feed and receiver. A study is in progress to determine whether high-gain antennas of different sizes should be carried on different missions or whether it is possible to meet the requirements of all the missions with a single antenna design. One or more low-gain antennas may also be included in the radio-frequency module for use during emergencies if the spacecraft cannot find the Earth.

The propulsion module provides the impulse for trajectory changes and the reaction control for maintaining the proper orientation of the spacecraft. Figure 3 shows the number of tanks necessary to provide trajectory changes of ~ 1 km/sec.

The power module accommodates a radioisotope thermoelectric generator (RTG) or a solar panel. The RTG is the power source of choice for the outer planet missions. Because an RTG is a source of radioactivity, it must be well shielded and located far away from the scientific instruments to minimize interference with their measurements. An RTG cannot be used at all on missions, such as an orbiter of Mars, in which gamma-ray spectrometers are carried for measuring the composition of the target body by analysis of the low flux of gamma rays that it emits naturally. For such missions the power source would therefore be a solar panel. Space must be set aside in the central module for the batteries required when the panels cannot be in sunlight. The power conditioning and handling equipment in the central module would be the same for all missions, independent of the nature of the power source.

The scientific instruments and attitude control sensors are located on the outside of the central module, on one or more fixed booms, or on an articulated platform. The booms are for instruments that must be isolated from interference associated with the main spacecraft. The articulated platform can rotate about either of two axes to allow the instruments on it to be pointed in almost any direction.

The final module would be a probe for a Titan or outer planet mission or the Earth-return capsule for the mission to return a comet sample. The large propellant tanks needed for interplanetary maneuvers would be jettisoned before the probe is released.

Figure 4 illustrates how the spacecraft could be reconfigured from one mission to the next. Figure 4C shows the probe-carrying configuration of Fig. 3. The configuration shown in Fig. 4A could be used for a Saturn orbiter. This mission requires additional propellant tanks, which fit in where the probe was located in Fig. 4C. Figure 4B shows a Mars orbiter configuration, similar to the Saturn orbiter except that a solar panel would replace the RTG power source, whose radiation would interfere with gamma-ray spectrometer observations. The antenna might also be smaller for a Mars mission than for a Saturn mission. The comet and asteroid rendezvous spacecraft would look like that shown in either Fig. 4A or Fig. 4B, depending on

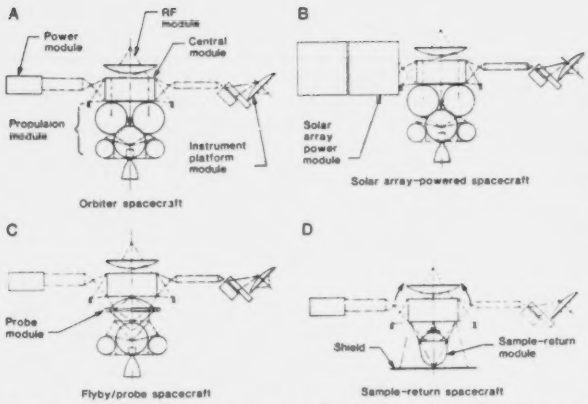

Fig. 4. Reconfiguration of the Mariner Mark II spacecraft from mission to mission. The arrows in (D) indicate two appendages that are to be folded away behind the dust shield during the comet encounter; *RF*, radio frequency.

whether a gamma-ray spectrometer is part of the payload and on how far from the sun the spacecraft must operate. (The latter, in turn, depends on which comet or asteroid is chosen as the target.)

The comet-sampling spacecraft (Fig. 4D) must fly through the cometary dust cloud at high speed. The spacecraft is protected from the dust by a shield and a sample collector. During the flyby the power module and scan platform must be folded back and hidden behind the shield. The shield must be pointed in the direction of the relative velocity vector. If it is necessary to maintain the telemetry link during the flyby, the high-gain antenna would have to be tipped toward Earth.

The requirement for high levels of inheritance and reconfigurability applies to more than just the major spacecraft appendages; it also applies to spacecraft subsystems and the scientific instruments. All missions with high-resolution imaging would use the same Galileo-derived camera design. The other instruments would be treated like "black boxes" as much as possible, with the smallest possible differences in the interfaces for the different instruments. This is made feasible and cost-effective, in part, by the increased use of microprocessors in individual instruments. All but one of the nine Galileo instruments contains a microprocessor. If each Mariner Mark II instrument temporarily stored its own data and formatted it into telemetry packets, the spacecraft data system would not have to be changed in response to changes in the instruments from one mission to the next. Each source-generated data packet contains a standard header identifying its source and length. The spacecraft data system then becomes simply a transportation and storage service. The ground-support system would be based on multimission standards and protocols to such an extent that changes in the science payload or in spacecraft subsystems would be transparent to the machines and people transporting the data. The ground system could support several missions simultaneously.

The modular approach reduces the impact of those changes that must be made. Costs for redesigning, retesting, and flight qualification are minimized. Modularity allows the introduction of new technology into the system piecemeal, as it is proved and qualified. A high level of inheritance enables block buys of items used in several missions. It also simplifies or eliminates the response of the ground system to changes in the spacecraft.

Design margins. To achieve reconfigurability and low cost, adequate design margins are crucial. Design margins provide increments of capability without affecting the overall system design. Adequate margins also lower costs by simplifying designs, manufacturing processes, operations, and sequencing; reducing the amount of performance analysis; and reducing the risk of cost increases associated with design changes.

With respect to Mariner Mark II, large margins have been applied in estimating the performance of its unproved launch vehicles. The analysis that generated the flight times given in Table 1 was based on the pessimistic assumption that the performance of the IUS and the Centaur will be only 80 percent of that expected.

With reasonable mass margins taken into account, the estimated mass of the basic Mariner Mark II spacecraft is about 600 kilograms, exclusive of the propulsion tanks, fuel, and any probes that may be carried. This total includes 97 kilograms for scientific instruments. The estimated mass of a spacecraft inevitably increases during the progression from preliminary design to actual construction. Mass reduction programs required by inadequate initial mass margins have been very expensive. But more important than leaving a margin to cover uncertainties is the ability to "waste" mass to make interfaces simpler and to reduce cost in other ways. The propulsion module is an example of how large mass margins could reduce the cost of the Mariner Mark II missions. If mass had to be minimized, the propellant tanks for each mission would be as small as possible. It would be less expensive, however, to design, build, and test only one or two sizes of tanks and to fill them only partially for missions that require smaller changes in trajectory.

Design margins can also help to reduce the cost of managing power, data storage, computing, and thermal control. For example, the ability to have all instruments and subsystems operate at their peak power levels simultaneously can eliminate a great deal of sequencing activity. Adequate data storage and computing capacities also reduce the amount of detailed planning, sequencing, and memory management.

New technology. Mariner Mark II will make full use of the current gap in planetary missions to take advantage of technical developments. New technology and advanced developments will be used to reduce costs, avoid problems of parts obsolescence, and achieve acceptable performance. The goal is to demonstrate technological readiness through engineering model demonstrations before the start of the project. Several new technologies studied thus far show promise for providing lower recurring costs and a net savings to the project. Examples include the following:

1) An all X-band telemetry system. The Voyager spacecraft receives commands from the ground at the S-band frequency of 2110 megahertz and transmits data in both the S band (~ 2300 MHz) and the X band (~ 8400 MHz). X-band data links are preferred because

directive antenna gain varies directly with frequency squared while noise caused by charged particles along the ray path is an inverse function of frequency squared. The Mariner Mark II two-way X-band system would not only have better performance than the Voyager system, but weight and cost would be reduced because it is simpler and requires less equipment to accommodate one frequency range than two.

2) Fiber-optic rate sensors (FORS) for use as an inertial reference system. A FORS-based inertial reference system has no moving parts and an inherently low drift rate. It might offer distinct cost advantages over the traditional gyroscopes once the integrated optic circuit can be mass-produced. It is expected that, beginning in the late 1980's, industry will invest heavily in the development of fiber-optic components and integrated optic circuits.

3) A multipurpose celestial sensor based on a CCD under microprocessor control. This sensor can image several stars simultaneously to provide a celestial reference for the spacecraft or can be used to track target bodies if mounted on the science instrument scan platform. Closed-loop pointing of this platform might be of particular advantage when the ephemeris of a target body is not well known and might lower costs by reducing sequence planning and platform pointing calibrations.

4) Very large scale integrated (VLSI) circuits. VLSI circuits may be used in command and data handling (CDH) and attitude control subsystems, in interface units between the CDH subsystem and the science instruments, and in other spacecraft subsystems. In one design approach for the CDH subsystem, self-checking computer modules incorporate VLSI and LSI components. VLSI circuits hold promise for reducing the cost, weight, power, and volume of electronic assemblies.

5) Image compression. This is another area where VLSI components could be employed. Newly developed data compression techniques and low error rates allow the number of data bits required to transmit a picture to be reduced by a factor of 1.3 to 4 (depending on the activity of the picture) without any loss of information. There are applications in which much larger compression ratios could be used to trade picture quality for a greater number of pictures. A recent study indicates that optical navigation data can be compressed by a factor as high as 100 without significant degradation of the needed information. Data compression techniques can have a significant impact on downlink telemetry rate, antenna size, transmitter power, and data storage capacity, and therefore on cost.

6) Electronic and optical disk data distribution. If cost-effective, the ground system for Mariner Mark II would allow investigators to have access to their data at remote terminals. This would obviate the need to generate and transport large quantities of hard-copy pictures and magnetic tapes to the data users. There will probably also be significant cost advantages in the use of digital optical disks, which can store an extremely large amount of data and can be reproduced at low cost.

Conclusion

The SSEC is outlining the scientific priorities for planetary exploration in the rest of this century. The Mariner Mark II is being developed to meet the requirements of the deep-space missions on the SSEC's list. The proposed spacecraft could be reconfigured at low cost from mission to mission and be supported by a simplified, multimission ground system. I believe that Mariner Mark II can meet its cost goal of $150 million to $300 million per mission. Discipline will be required to keep the objectives of each mission focused, to limit the complexity and performance of the spacecraft and ground system to the minimum levels required to meet the objectives, and to avoid the use of new technology before its flight readiness has been demonstrated.

After two decades of planetary exploration, we now have the knowledge and experience to select a set of deep-space missions of outstanding scientific value and to implement them at low cost.

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7. This article presents the results of one phase of research carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under NASA grant NAS 7-100. Most of the credit for the article's content belongs to the many participants in the Mariner Mark II study. Numerous members of the JPL staff also read the article and helped to improve its presentation. They all have my thanks.

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A Prelude to Interstellar Flight

By LEONARD D. JAFFE and HARRY N. NORTON
Jet Propulsion Laboratory, CalTech

Before we can think about flying to a star, we must learn how to fly beyond our planets; a star mission is still a dream, but an interstellar precursor mission could soon be a reality

Mankind's reach for the stars acquired a semblance of reality in the increasing achievements in space exploration during the past two decades. Since we are now in the process of exploring the outer planets of our solar system, it would seem appropriate to consider the scientific promise as well as the engineering problems of missions to the stars and, hopefully, their planets.

A brief calculation brings out the primary problem. It would take over 10,000 years to reach the nearest star, Proxima Centauri, at a distance of 4.3 light years (about 4×10^{13} km), if a spacecraft could be given a hyperbolic velocity for solar-system escape of 10^2 km/s (3×10^6 km/yr). Establishing such a spacecraft lifetime, or a much greater velocity, by the year 2000 does not seem possible. The star mission has to be shelved for the time being. But later in the 21st Century, as propulsion improves, it may be possible to make this flight in much shorter time; then it may become feasible.

What could be done in the meantime? In a symposium on "Missions Beyond the Solar System," organized by Louis D. Friedman and held at the Jet Propulsion Laboratory (JPL) in August 1976, the idea of a precursor mission out beyond the planets, but not nearly so far as another star, was suggested as a means of bringing out and solving engineering problems inherent in a star mission. At the same time it was recognized that such a precursor mission could also have significant scientific objectives. A small team was then organized to study the scientific benefits and technology requirements of an interstellar precursor mission.

Space science would, in fact, benefit significantly from such a mission. Characteristics of the heliopause (where solar wind terminates against incoming interstellar medium) and the interstellar medium could be determined by in situ measurements. Stellar and galactic distances could be determined with far greater accuracy through parallax measurements of nearby Cepheid variables using an Earth-to-spacecraft baseline. Cosmic rays having energy levels too low to penetrate the heliosphere could be detected and characterized. The solar system as a

THE AUTHORS

LEONARD D. JAFFE (AF), deputy manager of planetology and oceanography at JPL, received an SM from MIT and and ScD from Harvard. He has led materials research at Watertown Arsenal and JPL and was project scientist for Surveyor. In recent years he has been involved in lunar research and in studies of future space missions and Earth applications of space technology. **HARRY N. NORTON** (AF), a member of JPL's systems design and engineering staff, has worked on many space missions, including Mars sample return, the Jupiter orbiter with probe (Galileo), and instrumentation for a space-vacuum research facility. He has written a transducer handbook and numerous technical articles. After receiving a BEE from NYU in 1960, Norton began his career in aerospace engineering doing jet-aircraft design and then moved to space-booster instrumentation and spacecraft systems design.

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whole, such as its total mass and its internal (interplanetary) gas distribution, could be scoped from a vantage point external to the system. A secondary science objective could be a close-up determination of the characteristics of Pluto and its rings and satellites, if any.[2]

It was decided to concentrate on a precursor mission to a distance of 400 to 1000 AU. (Pluto, our outermost planet, will be about 30 AU from the Sun in the year 2000; Proxima Centauri is 270,000 AU away.) As the concept developed, the duration of the mission was planned as 20 years to reach a distance of around 400 AU. The mission could then be extended to about 50 years to reach a distance of more than 1000 AU.[1]

Engineering of this precursor mission would raise formidable challenges. Major advances in technology, particularly in propulsion and telecommunications and in overall reliability, would have to be attempted and then proven.

Trajectory and Propulsion Choice: Trajectory and propulsion-system selection are the prime design drivers of the precursor mission outward to 400-1000 AU, directed toward the incoming interstellar gas and including a Pluto flyby if possible. The Shuttle or, better, a Shuttle derivative able to deliver more payload was assumed as launch vehicle. Low thrust as well as Jupiter or Venus-Earth gravity-assist trajectories and combinations of these were considered. Low-thrust options examined included solar sailing,[3] laser sailing (with an Earth-orbital laser source illuminating the sails),[4] and solar-electric, laser-electric,[5] and nuclear (fission or fusion) -electric propulsion with ion or magnetoplasmadynamic drive. Some consideration was even given to the use of antimatter production as source of propulsive energy. Dual systems, such as solar-electric propulsion for earlier mission phases and nuclear-electric propulsion for later mission phases, were also studied.

The mission selected demands a heliocentric excess velocity (v_∞) well over 50 km/s. Maximum performance would be provided by an antimatter energy source.[6-9] This may eventually be feasible, but not for a launch in the year 2000. The options able to produce the required v_∞ by then will be solar or laser sailing and nuclear-electric propulsion.

The sail technique—propulsion derived from photon pressure acting upon very large, very-thin-film "sails" attached to a spacecraft—would require formidable technology developments.[10] For a year-2000 launch it may be possible to attain a sail surface with a mass-to-area ratio of 0.3 g/m^2 by making the necessary development effort. Such a sail could be a surface-treated aluminum film about 100 nm thick. It would probably have to be fabricated in orbit. The perihelion distance of the trajectory would have to be at least 0.25 AU to avoid overheating the sail. But it might yield a v_∞ of about 120 km/s.

Reducing the perihelion distance to 0.1 AU would increase the solar photon force, but also the sail temperature. Assuming a reflectivity of 0.9 and a total emissivity (sum for two sides) of 1.0, the sail temperature would reach 400 C. This would call for the use of high-temperature materials. An additional problem is posed by the emissivity itself. It may never be possible to attain 1.0 with a film mass of less than 1 g/m^2, because of the emitted-wavelength/thickness ratio. The emissivity of an 0.3 g/m^2 film would be 0.5 or less; this would increase the sail temperature to 600 C or more. Carbon films could stand such a high temperature, but it would be difficult to give them a highly reflective surface and their mass could most likely not be less than 1 g/m^2 (according to W. Carroll of JPL). Such a sail and trajectory could provide a v_∞ of less than 110 km/s, somewhat poorer performance than for the 0.25-AU perihelion distance case using lower-temperature materials.

In laser sailing the photons acting upon the sail come from a laser instead of from the Sun. The hypothetical case studied assumes an incident photon flux equivalent to 1700 "suns" at 1 AU.[11] A high sail reflectivity, perhaps 0.99, could be attained because the laser energy is monochromatic and interference layers could be used effectively on the film. Using such coatings, and assuming the high incident energy of 700 suns, the sail temperature and associated problems would be about the same as for the 0.1-AU perihelion solar-sailing case. However, if a laser source of sufficiently high power (20 megawatts average) could be built and placed in orbit, the spacecraft could attain a v_∞ of up to 200 km/s.

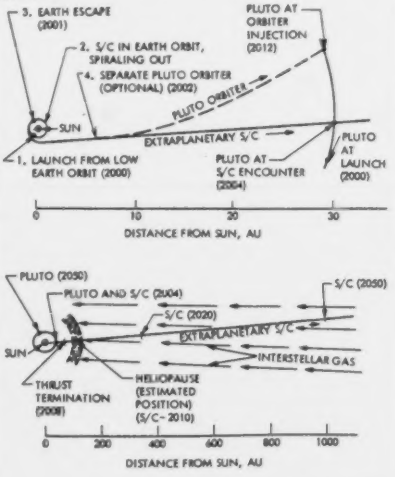
Fusion as well as fission reactors were considered for nuclear-electric propulsion (NEP). Rough calculations for a fusion system, based on today's limited knowledge, indicate a 30% improvement in v_∞ over a fission system, but at the expense of much larger spacecraft mass (perhaps orders of magnitude larger)[9] as well as probably a prohibitive cost. Moreover, net energy production by controlled fusion has not yet been attained, and development of an operational fusion propulsion system for a year-2000 launch is highly improbable. Collection of hydrogen en route to refuel a fusion reactor[12] stands even further in the future, and it may well never be feasible.[13]

NEP systems using fission have already been the subject of considerable study and some advanced development.[14,15] Designers have more confidence that NEP systems can meet the performance requirements than the other options examined. Preliminary calculations showed that one NEP stage could yield a v_∞ above 100 km/s.

After weighing the pros and cons of these several propulsion options, we chose fission NEP for the baseline extraplanetary spacecraft and its mission.

Mission Design: Both scientific goals and spacecraft performance shaped characteristics of the extraplanetary mission.[1,2]

F-1 TRAJECTORY OF EXTRAPLANETARY SPACECRAFT
For baseline interstellar precursor mission. Expanded-scale Earth-Pluto portion includes separation and trajectory of optional Pluto orbiter. Time of major mission events is based on launch in year 2000.



T-1 MASS AND PERFORMANCE ESTIMATES FOR BASELINE EXTRAPLANETARY SPACECRAFT
For single- and two-NEP-stage versions, including the optional Pluto Orbiter; I_{sp} and propellant loading not yet optimized.

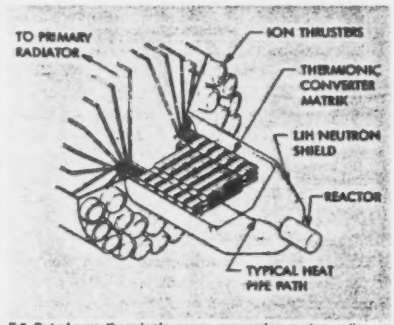
Allocation	Mass, kg	
Spacecraft (without power and propulsion)	1200	
Pluto orbiter	1500	
Propulsion, dry (NEP, 500 kw_e)	8500	
Propellant (Hg): spiral from Earth orbit	2100	
heliocentric trajectory	18100	
Propellant tankage	600	
Total mass in Earth orbit, 1 stage	32000	
Booster stage (2 × 500 kw_e NEP)		58000
Total mass in Earth orbit, 2 stages		90000
Performance	**1 Stage**	**2 Stages**
Distance at booster burnout, AU	—	8
V_∞ at booster burnout, km/s	—	25
Time from launch to booster burnout, yr	—	4
Distance at spacecraft NEP burnout, AU	65	155
V_∞ at spacecraft NEP burnout, km/s	105	150
Time from launch to spacecraft NEP burnout, yr	8	12
Spacecraft distance in 20 yr, AU	370	410
Spacecraft distance in 50 yr, AU	1030	1360

Most of the scientists consulted favored a trajectory that would take the spacecraft out of the solar system as rapidly as possible. This would provide a relatively early opportunity to obtain measurements of the heliopause and the interstellar medium. It would also place the spacecraft at a large enough distance from Earth to permit optical determinations of stellar parallax within a reasonable period after launch. Pluto observations were also deemed desirable.

Salient spacecraft performance goals includes a 20-year design lifetime and a 50-year extended lifetime, a heliocentric excess velocity of around 100 km/s, appropriate science instrument pointing provisions, and a telecommunications system adequate for data transmission and command reception to a distance of 1000 AU.

In the resulting mission design (F-1) the spacecraft, with or without a second NEP stage, would be placed into a low Earth orbit by some descendent of the Shuttle (an alternative would be the use of two or more Shuttle launches and space assembly of the vehicle). NEP then drives the spacecraft through an Earth-escape spiral. Thrusting continues as the spacecraft flies along a heliocentric-orbit trajectory. It takes a long "burn" to attain the required v_∞: about 8 years with a single NEP stage and close to 12 years with two. The thrusters would be shut off during Pluto flyby as well as during other periods when the exhaust would interfere with scientific measurements. Enough propellant would be retained after the main period of propulsion to permit using thrusters for attitude control (unloading the reaction wheels). The reactor would be kept operating at low power for this purpose as well as for keeping non-propulsive spacecraft subsystems operating during the whole mission.

The spacecraft heads toward the incoming interstellar gas. By coincidence, Pluto will be very close to the selected trajectory during the 2000-2005 period. This makes an enroute Pluto encounter feasible. The encounter could be just a flyby; or, if more information about Pluto is to be obtained, a Pluto orbiter could be carried by the main (extraplanetary) spacecraft and be separated early in the mission. The Pluto orbiter would be a full-up spacecraft, with sufficient chemical propulsion to handle midcourse corrections, approach, and orbit injection. It would carry a full complement of science instruments (including imaging), would be powered by RTGs (radioisotope thermoelectric generators) and would communicate directly with Earth. Its flight time to Pluto would be about twelve years and its approach velocity at Pluto would be about 8 km/s. Since the extraplanetary spacecraft would fly by Pluto about eight years before the Pluto orbiter reaches it, the flyby data could be used for orbit optimization.



F-2 Out-of-core thermionic power conversion system relies on about 100 heat pipes to transfer heat generated by the nuclear reactor to thermionic converters (six per heat pipe). After conversion of thermal to electrical energy, the remaining heat is carried to the primary radiator for dissipation. Illustration after Phillips and Pawlik.[19]

Some thought was also given to an additional mission, suggested by some of the scientists contacted, in which a spacecraft similar to the baseline vehicle (but without Pluto orbiter) would be flown outward parallel to the solar axis, a trajectory essentially perpendicular to that of the heliocentric baseline mission. Such a mission would require somewhat more propulsive energy to attain the same v_∞. Thus a Jupiter swingby might be helpful

in it. A second NEP stage would be more advantageous for this mission than for the baseline mission.

Mass and Propulsion System: T-1 gives spacecraft mass and performance estimates. A mass of 1200 kg was allocated to nonpropulsive, nonpower-generating portions of the spacecraft; this covers all the usual subsystems and structures such as booms, electronics bus, orbiter supports, and NEP interfacing. Science instruments, scan platforms, and telecommunications equipment would weigh more than for typical outer-planet missions studied by JPL. An allowance was included for radiation shielding. Telecommunications could require as much as 1 kw of electrical power; nonpropulsive spacecraft power was thus set at about 1500 w.

The Pluto orbiter's mass, 1500 kg, includes about 1000 kg of chemical propellant representing a ΔV of 3500 m/s (allowing a good capture orbit at Pluto).

The NEP—a 500-kw_e system with 20% conversion efficiency—would consist of a nuclear reactor, reactor controls, a coolant system, radiation shielding, thermionic converters, radiators, power conversion and conditioning, and ion thrusters (see F-2). Such a system would have a dry mass of about 17 kg/kw_e for an exhaust velocity of 100-140 km/s. We chose mercury propellant because of its high liquid density (13,600 kg/m^3) and its very effective gamma-ray shielding. An NEP booster would employ two of these 500-kw_e units.

The reactor would be designed for a fuel burnup equivalent to 200,000 hr at full power, of which 70,000 (8 yr) would be at full power, and the remaining 130,000 hr at about one-third power (scaled linearly, equivalent to 390,000 hr, or 44 yr, of reduced power operation). Major improvements in reactor controls as well as adaptive control for power and propulsion functions will be required to attain such reactor operation.

The total initial mass in low-Earth orbit (32,000 kg without the second NEP stage) is larger than the currently established Shuttle payload limit (29,500 kg). However, a vehicle able to launch substantially heavier payloads should be available in the 1990s.[9] Hence, we assume the baseline spacecraft requires only a single launch. Space assembly would probably be required to add a second SEP stage.

Data Handling and Telecommunications: Establishing a reliable telecommunications link for an extraplanetary mission out to 1000 AU should, ideally, be based on technological advances anticipated to occur during the next twenty years. We believe developments will surely permit an X-band system with 40 w of transmitter power, a 15-m-diam spacecraft antenna, and a 100-m receiving antenna on Earth as a reference system, providing 100 b/s at 1000 AU. The 100-m antenna would be supplied by the NASA Deep Space Network (DSN).

For a mission lasting between 20 and 50 years, with relatively little happening most of the time, it would be unreasonable to expect continuous DSN coverage. For the long cruise periods a 1% coverage (8 hr per month) would probably be sufficient. This poses the need for onboard data processing (compression) and storage, with playback and transmission at a relatively high rate in brief periods. During heliopause encounter the coverage may have to be increased to as much as 8 hr per day. For Pluto flyby continuous coverage would probably be required. Coverage for the Pluto orbiter would be either 8 or 24 hr/day for at least some of the mission of the orbiter.

Onboard adaptive data-acquisition, data-processing, and data-compression techniques would be employed to minimize the rate of transmitting data from the spacecraft. Even with these features, data rate should average 20-40 b/s. With 1% coverage, this corresponds to a transmitted data rate of 2-4 kb/s. Several approaches could provide this transmitted data rate:

—More spacecraft transmitter power (500 to 1000 w).

—A 300-m-diam receiving antenna located on an

T-2 DATA RATES FOR TELEMETRY SYSTEM ALTERNATIVES
Transmittable data rates are shown at distances of 1000 AU (50-yr mission), 400 AU (20-yr mission), 150 AU (worst-case assumed end of heliopause), and 31 AU (Pluto); noise temperature of 10 K for X-band, 14 K for K-band.

Option	Improvement over baseline, dB	Data rate × range^2, b/s-AU^2	Data rate, (b/s)			
			1000 AU	400 AU	150 AU	31 AU
Reference system (40 w, X-band, 100-m receiving antenna)	—	1×10^6	1×10^2	6×10^2	4×10^3	1×10^5
More xmtr. power (500-1000 w)	10-15	1×10^9	1×10^3	6×10^3	4×10^4	1×10^6
300-m ODSRS antenna:						
At X-band	13	2×10^9	2×10^3	1×10^4	9×10^4	2×10^6
At K-band	17	5×10^9	5×10^3	3×10^4	2×10^5	5×10^6
More power plus 300 m ODSRS, X-band	23-28	3×10^{10}	3×10^4	2×10^5	1×10^6	3×10^7

Orbiting Deep Space Relay Station (ODSRS).[16]

—Transmission via K-band, instead of X-band, to the ODSRS.

T-2 shows the improvements made possible by these options.

Spacecraft Configuration: F-3 depicts a first-cut conceptual configuration of the extraplanetary spacecraft. We assumed a furlable "wrap-rib" design for the 15-m antenna. The annular feed for the antenna surrounds the power-processor radiator. This feed design allows transmission aft along the thrust vector and around the high-energy-particle stream from the ion thrusters.

The entire portion of the spacecraft aft of the antenna involves the NEP system, including the power processor. Some spacecraft equipment could be placed in the transition structure between the power-processor radiator and the antenna hub.

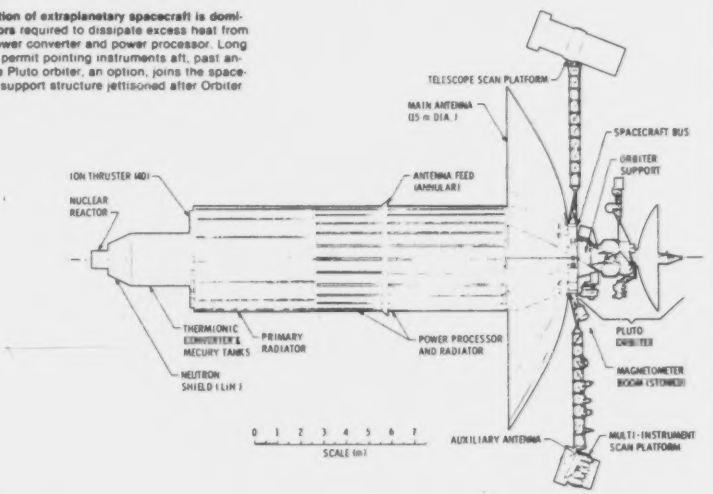
The spacecraft bus carries the electronics, including celestial sensors for attitude-control referencing. Reaction wheels and ion thrusters control attitude. The outer of two concentric sets of thrusters would be gimballed for this purpose.

Support structures for the Pluto orbiter and the two deployable science booms are mounted to the spacecraft bus. The orbiter would be separated from the forward end of its support (the structure later being separated from the bus and jettisoned).

The extendable magnetometer boom, in its stowage canister, attaches to the boom-support structure. Sensing elements of the vector magnetometer, used for magnetic field measurements and mounted at and near the boom tip, thus ride at a distance from the spacecraft-induced magnetic field when the boom is extended. Other scientific equipment (included on a "strawman" list of potential science instruments[2]) either ride on a boom or on one of two scan platforms. The boom-mounted instruments measure plasma properties and electric fields, characteristics of interstellar dust and gas (mass spectrometer), and low-energy cosmic rays.

The telescope scan platform carries a single instrument, the long-focus TV camera, which has a 1-m-diam objective 3.5 m long. A short-focus camera, also with a 1-m-diam objective, rides the multi-instrument scan platform. Both platforms can be rotated about two axes.

Five additional instruments (from the "strawman" list) are mounted to the camera's support clamp on the multi-instrument platform: a microwave radiometer (to sense radiation temperature), a gamma-ray transient detector, an ultraviolet/visible spectrometer, and two instruments used mainly during Pluto flyby—an infrared radiometer and an infrared spectrometer. This platform also carries an auxiliary antenna, possibly articulable independently; it would be used during early mission phases when the main antenna does not point directly at Earth. Antennas needed for a radio-as-



F-3 Configuration of extraplanetary spacecraft is dominated by radiators required to dissipate excess heat from NEP reactor, power converter and power processor. Long science booms permit pointing instruments aft, past antenna edge. The Pluto orbiter, an option, joins the spacecraft through a support structure jettisoned after Orbiter separation.

tronomy/plasma-wave receiver would extend from the spacecraft bus.

The Pluto orbiter (F-3) has a configuration based on the Galileo spacecraft (Jupiter orbiter with probe) now being developed by JPL. Its instruments would include a TV camera, a gamma-ray spectrometer, and many of the instruments also carried on the extraplanetary spacecraft.

Developments Needed: Several areas of technology would require significant development to enable an interstellar precursor mission with a launch in the year 2000. These include primarily design and fabrication techniques that can provide a 20-50-year lifetime for spacecraft subsystems and components (including moving parts such as bearings) and application of quality assurance and reliability prediction methods utilizing test times much shorter than the intended lifetime. Current low-level development efforts in NEP systems would have to be expanded to provide a long operating life at full power and a much longer operating life at reduced power. For solar or laser sailing to be considered for such a mission, appropriate materials and systems would need to be developed. Antenna-pattern problems associated with the annular feed would need to be investigated; and optical (laser) communications instead of RF should be looked into as a possible alternative. Some science-instrument development would be needed, and instrument compatibility with NEP would have to be examined.

We have the motive for this: man reaching out to a star. A mission out of the planetary system, with launch about the year 2000 could provide valuable scientific data as well as test some of the technology for a later mission to a star. Most critically needed will be technology that can yield a 50-yr spacecraft lifetime and a long-life NEP system.

Acknowledgement

Many persons contributed to the ideas expressed in the article. We wish to thank especially the other members of the JPL study team which worked out the conceptual design for the interstellar precursor mission and the extraplanetary spacecraft: C. V. Ivie, J. C. Lewis, R. Lipes, J. W. Stearns, L. D. Stimpson, and P. Weissman. We also thank W. F. Carroll and C. Uphoff for their contributions regarding solar and laser sailing. This work was sponsored by the Study, Analysis and Planning Office of the NASA Office of Aeronautics and Space Technology under Contract NAS 7-100.

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Effective Planetary Exploration at Low Cost

By JESSE W. MOORE
NASA Office of Science and Applications
Earth and Planetary Exploration Div.

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In NASA's planetary exploration program for the '80s the Galileo mission, now in its fabrication stage, may well be the sole successor to the Mariners, Pioneers, Vikings, and Voyagers of the '70s. Funding for the planetary program has reached an all-time low of less than a third of its peak, and five budget years have passed since the start of Galileo.

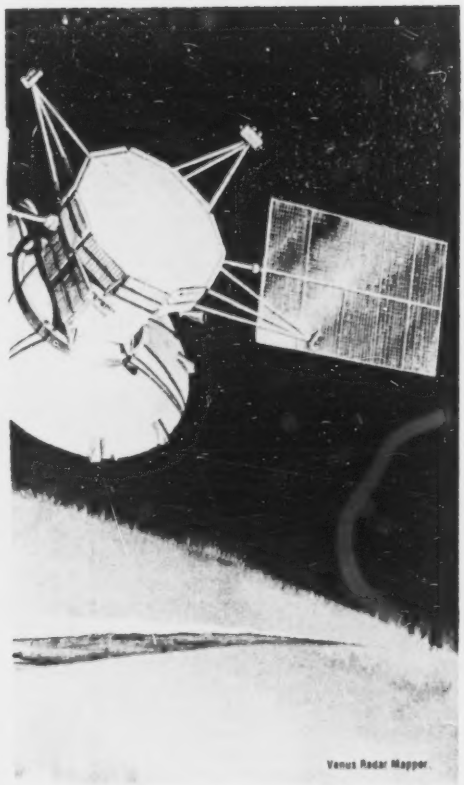
Turning this downtrend around, most would now agree, requires finding ways of making solar-system exploration as inexpensive and cost-effective as possible. This has been an aim of the Solar System Exploration Committee (SSEC), an ad hoc advisory group working for the past two years (see box). With the support of NASA Ames Research Center and the Jet Propulsion Laboratory (JPL) it has examined various ways to reduce costs for planetary missions. This article describes efforts to reduce costs of planetary missions. Approaches drawing in good part on existing hardware, but also including new technologies, hold great promise for revitalizing the planetary program.

Background: The significance of relatively low-cost missions presently under study can only be appreciated by looking back at the course of the planetary program. It began opportunistically, taking as ready and obviously alluring targets the planets Venus and Mars. The first four U.S. deep-space projects achieved two flybys of Venus and three of Mars. The spacecraft were derived from the lunar-exploration Rangers.

Meanwhile, the Apollo manned lunar landing program emerged. Apollo eclipsed brilliant successes of unmanned Lunar Orbiters and Surveyors. Direct sample return by Apollo crews proved the most comprehensive and powerful technique for planetary exploration, and the laboratory analyses used to study the lunar samples were immediately applied to large numbers of planetary samples (meteorites of unknown parentage) in museums. The combined results give us far-reaching knowledge about the origin of the solar system.

Telescopic techniques progressively opened another important avenue to exploration of the solar system. Planetary astronomy has done much science that might otherwise have called for spacecraft reconnaissance and has surveyed areas still unexplored by spacecraft, the comets, and asteroids.

As Apollo ended, planetary exploration surged into an extraordinary pioneering period. The missions of the '70s pushed inward to Mercury and outward to Jupiter and Saturn, and they took on the extraordinary challenge posed by the search for life



Venus Radar Mapper

Sticking to the main scientific objectives, using derivative designs and hardware, and strictly limiting modifications will permit a relatively inexpensive planetary program of sweep and effectiveness

on Mars, a goal calling for technical innovation of the highest order.

Marvelous but very expensive machines wrote the first chapter in planetary exploration. Deep-space mission results were combined with telescopic discoveries and lunar-sample and meteorite analyses to create a broad, solid base of experimental data and an array of testable models of solar-system origin and planetary evolution. Thus the development of a *systematic* scientific strategy for exploration of the solar system became possible.

Beginning in 1974 the Space Science Board (SSB) of the National Academy of Sciences took on this task. To NASA it recommended strategies for exploration of the outer planets, the inner planets, and the primitive bodies—the comets and asteroids. The apparent absence of life at the two Viking landing sites on Mars caused the SSB to recommend against direct follow-ups to the Viking biology experiments, thus creating a major branching point for the planetary program.

SSB Recommendations: As a general strategy the SSB recommended that exploration move forward on a *broad front,* beginning with reconnaissance to all accessible planetary bodies, progressing to exploration of selected planets, and intensively studying a limited number of bodies. It recommended reconnaissance of parts of the solar system "where ignorance is greatest and the opportunity for new discovery is large."

The SSB set out in some detail the questions that should be addressed by planetary missions and provided guidance about priorities. Achieving all the SSB goals would call for a powerful program of some diversity—one that would include the whole range of automated exploration techniques: remote sensing orbiters, atmospheric probes, surface landers, mobile labs, and sample-return spacecraft.

Omitting the latter two permits a technologically much less ambitious program within available launch capability (the two-stage Inertial Upper Stage (IUS) or the Centaur) and using approaches successfully demonstrated.

Options for Missions: On this basis, formulating mission strategy can be reduced in large part to a question of cost-effectiveness in missions of a well-understood character. The strategy could use three different approaches—

—Use of existing space hardware (including Galileo's).

—Modification of "production-line" spacecraft developed by aerospace companies for scientific and commercial use in Earth orbit.

—Development of a new modular spacecraft allowing a series of missions beyond the orbit of Mars.

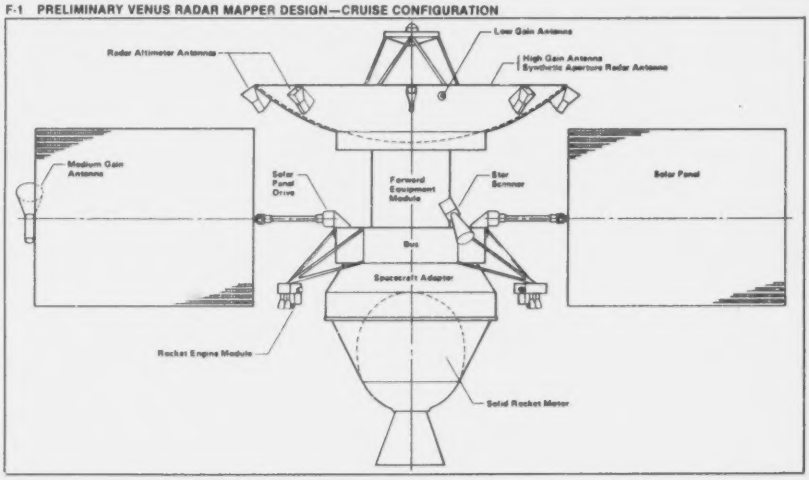
The Venus Radar Mapper (VRM): Already endorsed by the Solar System Exploration Committee and by the Space Science Board and an attractive candidate new start for FY84, the VRM mission fits the first category.

Usually a planetary project begins with fundamental scientific questions. These set requirements of the mission, spacecraft, and sensors. Ordinarily, many special subsystems must be developed to meet the requirements. This makes project costs high.

VRM's project constraint of low cost necessitated a different approach. Practices consistent with previously established overall strategies for the exploration of the inner planets defined VRM—making fullest possible use of proven designs and existing hardware, limiting mission objectives, and trading off objectives with the requirement to use existing designs. A willingness to reduce a requirement to permit use of an existing design proved essential to low cost for VRM.

The prime objectives could be met by a spacecraft synthesized largely from existing designs. Using the Voyager antenna for both the SAR (Synthetic Aperture Radar) and the telemetry link typifies the trade-offs made. Image quality and swath width were compromised by this selection. The downlink data rate was constrained by the antenna, an X-band using open-loop pointing. A further constraint was the desire to avoid Deep Space Network (DSN) development costs by restricting the data rate. Together, these constrained the quantity of data and SAR resolution. The Command and Data System (CDS), a Galileo subsystem, likewise imposed limits in data and command rate. Nevertheless, the preliminary system assessment, performed by Hughes Aircraft, confirms that, while the compromises do not allow full advantage to be taken of SAR, they yield a design that meets all requirements.

F-1 PRELIMINARY VENUS RADAR MAPPER DESIGN—CRUISE CONFIGURATION



A spacecraft design formulated from these and other trade studies can meet broadly endorsed mission objectives at minimum cost. F-1 shows a preliminary spacecraft layout developed by Martin Marietta and JPL based on tradeoff analyses performed to date. It maximizes use of hardware and software designs from the Voyager, Galileo, and International Solar Polar (ISPM) missions. Simplicity is obtained through shared use of the fixed high-gain antenna and by limiting articulation to single-axis rotation of two solar arrays. The spacecraft embodies much existing equipment and design:

- It uses the CDS from Galileo with a minor modification (e.g., a timing circuit to produce the required telemetry rates and CDS flight software with minor modifications).

Solar System Exploration Committee (SSEC) Translates Scientific Strategy into Missions

The SSES, an ad hoc committee of the NASA Advisory Council, was formed in 1980 to "translate the scientific strategy developed by the Space Science Board of the National Academy of Sciences into a realistic, technically sound sequence of missions consistent with that strategy and with resources expected to be available for solar system exploration... to focus its initial efforts on those missions planned for initiation in FY84 and then extend its considerations as far into future as possible."

The SSEC has the following membership:

Noel Hinners, Chairman
Geoffrey A. Briggs, NASA, Executive Director
Arden Albee, CalTech
Kinsey Anderson, UC-Berkeley
James Arnold, Univ. of San Diego
Charles A. Barth, Univ. of Colorado
Thomas Donahue, Univ. of Michigan
Lennard A. Fisk, Univ. of New Hampshire
Harold P. Klein, NASA Ames Research Center
Eugene Levy, Univ. of Arizona
James Martin, Martin Marietta Corp.
Harold Masursky, U.S. Geological Survey
David Morrison, Univ. of Hawaii
John E. Naugle, Fairchild Corp.
John Niehoff, Science Applications Inc.
Tobias C. Owen, SUNY/Stony Brook

The initial recommendations of the SSEC should have been formulated by the end of last month. A further year of study directed at the definition of additional options for planetary exploration is anticipated.

• The attitude and articulation control subsystem is structured around the Galileo's processor, memory modules, and power supply. Inertial-reference-unit design has been flight-proven by several programs, and the star scanner is the same model used on the Boeing IUS. The Sun sensors and associated electronics are unmodified flight-proven designs, and the reaction wheels are of NASA standard design.

• The electrical power subsystem employs two single-axis articulated solar arrays using flight-proven solar cells on conventional substrates. Related parts come from Galileo. The power control unit and shunt regulator are flight-qualified hardware designs from an Air Force satellite. The two 20-ah batteries are of NASA standard design.

• The telecommunications subsystem uses the 3.7-m Voyager high-gain antenna, two Viking low-gain antennas, and a single Mariner medium-gain antenna. ISPM (residual) traveling-wave-tube amplified assemblies serve X-band high-rate communications. NASA standard deep-space transponders are used with a Voyager control unit. Flight-proven switches and filters isolate and switch circuits.

• The thermal-control subsystem uses flight-proven louvres, multilayer blankets, and heaters.

• A Star 48 solid-propellant rocket motor (SRM) powers orbit insertion at Venus. Four residual (178-N thrust) hydrazine monopropellant engines make trajectory-correction maneuvers. Orientation during the SRM thrust is controlled by these four engines augmented by four 445-N engines and four 22-N engines, all of which have extensive flight history. Twelve (residual) 0.9-N thrusters from Voyager dump momentum through the mission. The propulsion subsystem is operated in a blowdown mode from a single Shuttle auxiliary propulsion tank. Additional pressurant is stored in a small Galileo residual tank for a one-shot recharge prior to orbital injection at the planet. Flight-proven ordnance valves and latch valves isolate propellant tanks to meet the Shuttle safety requirements.

JESSE MOORE directs the Earth and Planetary Exploration Div. of NASA's Office of Space Science and Applications. After graduating from the Univ. of South Carolina in 1964 with an M.S. in electrical engineering he joined General Dynamics, where he worked on naval missile guidance systems. Between 1966 and 1978 Moore worked at CalTech's Jet Propulsion Laboratory (JPL) on guidance and control, advanced programs, and flight projects. Before assuming his present position he directed the Office of Space Science's Spacelab Flight Div.

The Venus Radar Mission retains as its primary goal a low-resolution (< 1000 m) map of the planet's surface, with additional gravity and altimetry mapping. By these hardware adaptations it should meet this objective for only $280 million (in FY83 dollars).

At its June 1982 meeting the SSEC endorsed this Venus Radar Mapping mission in the following statement:

"A principal scientific objective of inner solar system exploration is to understand the nature and evolution of the interiors, surfaces, and atmospheres of the Earth, Venus, and Mars. These three planets are of similar size and formed in the same region of the solar system, but have evolved to extremely different present states. In order to advance our knowledge of the formation and the evolution of terrestrial-planet surfaces, including Earth's, the next major step in exploration of the inner planets is the global reconnaissance of Venus's surface features to ascertain the processes and geologic history by which the surface has evolved. Because of the ubiquitous cloud cover on Venus, orbital observation with an imaging radar system is the only feasible approach. The SSEC reaffirms that an orbital imaging radar mission to Venus remains

of highest priority.

"Early in its deliberation the SSEC adopted the philosophy that in the present economic environment planetary missions cannot successfully be achieved without instituting a wide range of cost-cutting measures, acknowledging that scientific requirements might have to be tempered during this time to accommodate such measures. These measures include, for example, utilization of existing hardware, design and technologies, simplification of mission operations, and reduction of data rates and other spacecraft demands commensurate with essential scientific needs.

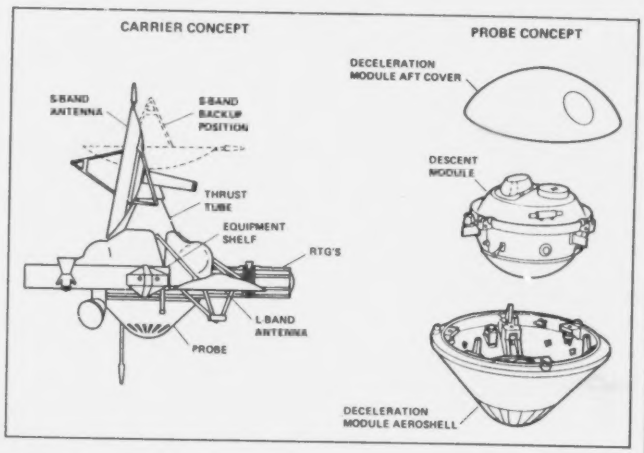
"The Venus Radar Mapper Mission, as presently conceived, has capitalized on this cost-saving approach. While reduced in scope from the original plan for the Venus Orbiting Imaging Radar Mission, the mission will reveal important information needed to continue our comparative studies of Earth, Venus, and Mars. Although global coverage and resolution are somewhat reduced, the Venus Radar Mapper Mission has included several adaptive features which are improvements over the earlier design. The SSEC strongly supports the Venus Radar Mapper Mission as a new start for FY84."

Low-Cost Outer Planet Probes: The first category of low-cost mission approaches includes not only the use of existing space hardware but also the hardware in production for the Galileo mission. Outer-planet missions being studied borrow heavily from the Galileo probe design. Science goals formulated in the light of Voyager results can be effectively addressed using minimal flyby missions with in situ sampling by atmospheric probes.

The principal science goals for entry probes in Saturn and Titan missions would be to determine the molecular and isotopic composition and structure of the atmospheres, the composition and structure of aerosols in them, and their sources of energy and associated organic chemistry.

Science goals for the probe-carrier and data-relay spacecraft include a determination of the physical nature of the surface of Titan, magnetospheric and

F-2 OUTER PLANET PROBE/CARRIER CONCEPTS



T-1 PROBE STRATEGY

Item/subsystem	Galileo probe, kg	Saturn probe, kg	Titan probe, kg
Deceleration module (DCM)			
Heatshield subsystem	170.2	57.2	16.0
Structure subsystem[a]	30.2	30.2	30.2
Instrumentation/harness subsystem	3.1	3.1	3.1
Parachute subsystem	8.1	8.1	8.1
Separation subsystem	3.9	3.9	3.9
Balance mass	3.6	3.6	3.6
Total DCM	219.1	106.1	64.9
Descent module (DSM)			
Communications subsystem	12.9	12.9	12.9
Command/data handling subsystem	16.7	16.7	16.7
Power subsystem	13.1	13.1	13.1
Structure subsystem	34.5	34.5	34.5
Harness subsystem	8.9	8.9	8.9
Parachute jettison modification	— —	7.7	7.7
Science instruments	25.0	25.0	29.4
Total DSM	111.1	116.8	123.2
Pre-entry science	— —	— —	23.8
Contingency (20% new units and instruments)	— —	3.7	8.5
Total separated mass	330.2	228.6	220.4

[a] Includes thermal control.

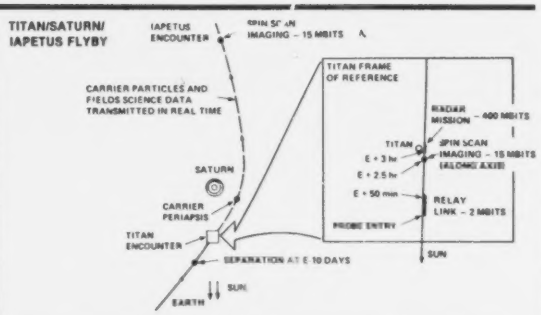
Probing Titan's Atmosphere

The proposed 1990 Titan Probe/Flyby mission commences with a Shuttle launch to Earth orbit during the March launch window. Either the Centaur upper stage or a three-stage stack of solid motors boosts the spacecraft from Earth orbit into the direct heliocentric transfer to Saturn. After a heliocentric transfer lasting about 3.5 yr, it reaches Saturn in August of 1993. The approach to Saturn is generally in a direction toward the sunlit face and toward the northern hemisphere 10-20° above the plane of the rings.

Using Earth-based radio doppler and ranging data, the carrier/probe spacecraft combination is directed toward a (probe) impact trajectory of Titan on the inbound hyperbolic fall toward Saturn. After its close encounter with Titan the carrier spacecraft will proceed on a trajectory past Saturn to a near encounter with Iapetus on the outbound leg of the hyperbolic flyby of Saturn. The appropriate position for Titan is thus in the direction of the Sun from Saturn.

Radio tracking and small propulsive maneuvers during the fall toward Saturn until ten days before reaching Titan allows the carrier/probe spacecraft to be targeted to a direct 90° impact with Titan with a one-sigma dispersion of about 500 km. At this point the probe is released and the carrier spacecraft is deflected and slightly decelerated in order to miss Titan by 2000 km and lag behind the probe by about 10,000 km to aid relay communication as the probe descends.

At 5000 km above the edge of the atmosphere of Titan, pre-entry science measurements will be started on four exterior mounted instruments that sample the upper atmosphere. Measurements continue to an altitude of about 700 km, where atmospheric heating begins to degrade instrument performance, at which time the externally mounted instruments are actively separated from the body of the probe.



The probe undergoes atmospheric entry heating and deceleration from an entry speed of about 10 km/sec to sonic speed at an altitude of about 100 km. The maximum deceleration will be about 24 *g* (Earth). Shortly thereafter, a parachute is deployed to extract the descent module from the forward heat-shield and thus expose the science instruments to the atmosphere. The five science instruments of the descent payload would be atmospheric structure instrumentation (ASI) with accelerometers and temperature and pressure sensors, a neutral mass spectrometer, a gas-chromatograph, a nephelometer to measure particle-size distribution in clouds, and a descent imager to take both upward and downward light-intensity measurements and to image the surface from an altitude of about 8 km.

During closest approach a synthetic-array/real-array hybrid imager mounted on the spinning carrier spacecraft makes a single image of 17% of the surface of Titan. Surface resolution will average about 6 km. In addition, radio occultation measurements of the atmosphere of Titan will be made.

Following the encounter with Titan, a small propulsive maneuver adjusts the trajectory of the carrier spacecraft to proceed to an encounter with Iapetus (less than 100,000 km) for making spin-scan visual images of the anomalous light and dark faces of that satellite. Surface resolutions of better than 10 km appear feasible.

high-energy-particle science, Saturn ring and system-dust measurements, and imaging reconnaissance of satellites poorly viewed by Voyager 1 and 2 (e.g., Iapetus or Phoebe). See above for a brief description of the Titan probe mission.

Following missions to Titan and Saturn, the low-cost outer-planet-mission set would be rounded out with flybys and probes to Uranus and Neptune.

Such missions would retain program continuity and science value by—

—Requiring each mission to focus on a limited set of science objectives.

—Using spacecraft with a very high degree of hardware component or design inheritance from existing spacecraft.

—Strictly adhering to a design-modification philosophy which requires minimum changes.

—Treating the outer-planet-mission set as a *single project* that postulates efficient "block-buy" of hardware components.

Under contract to NASA-Ames, Hughes Aircraft studied this approach by drawing on Galileo to meet SSEC goals. F-2 shows the probe concept used. It is very similar to the Galileo probe. The carrier spacecraft reflects a design concept proposed to NASA for Galileo at the time the agency considered splitting the mission into separate probe and orbiter launches. The spin-stabilized spacecraft has a despun steerable high-gain antenna with a separate, fixed probe-relay link antenna. It uses much hard-

ware from other NASA spacecraft and various commercial communication-satellite programs.

The probe follows Galileo design for Saturn and Titan with very few changes (T-1). The heatshield subsystem of the deceleration module causes the principal difference in weight. Galileo must handle a relative entry velocity of about 47 km/sec as compared to 29 km/sec for Saturn and only 10 km/sec for Titan. The structural subsystem remains unchanged and thus offers a large margin of safety. The communication and power subsystems would also be unchanged, resulting in a very large link margin at Titan, where the communications range between the probe and carrier is relatively small. A small modification allows jettisoning the parachute from the descent module (not done on Galileo) to reach the water clouds on Saturn at a pressure level of 10 bars and to descend to the surface of Titan in a reasonably short time.

The instrument complement for Titan would be changed to include a gas chromatograph (GC) to analyze organic molecules. Since the data rate and command structure of the probe would be unchanged, and since shelf space is required to mount the GC, two current Galileo experiments must be removed, possibly the helium abundance detector and the lightning and radio-emission detector. Finally, the Titan probe would add an externally mounted pre-entry science package to sample the upper atmosphere.

SSEC-guided study effort over the past year supports such hardware and design choices for meeting science objectives. Several upper stages can be used to launch such missions with the Shuttle. Centaur or a three-stage stack of existing solid motors (two SRM-1s and a STAR 48) allow direct missions about 3.5 yr long to Saturn and then Titan. Trip times to Saturn/Titan of about 6 yr are possible with the two-stage IUS and a STAR 48 or a two-stage stack of SRM-1s.

The SSEC believes a sequence of outer-planet missions concentrating at first on Saturn and Titan makes effective use of Galileo inheritance and available launch opportunities. This sequence includes a 1990 Titan probe/flyby, a 1991 Saturn probe/flyby, a 1992 Neptune probe/flyby (Jupiter swingby), and a 1993 Uranus probe/flyby (Jupiter swingby).

The first mission would cost about $190-270 million (constant FY83 dollars with a 20% contingency and not including launch vehicle or operations costs) depending upon the amount of scientific equipment carried over and above the basic probe payload. Subsequent missions would cost significantly less as a result of high inheritance.

Closer to Earth—a New "Pioneer" Class: Another category of lower-cost missions seeks to benefit not only from "heritage," but also from modification of existing "production-line" spacecraft developed by aerospace companies for both scientific and commercial applications. The missions would be tightly focused in terms of science goals and instrument payloads. As much as possible they would use modifications of Earth-orbiting spacecraft (in production at a time compatible with the planetary program start). R&D costs for the spacecraft would thus be virtually nil. Hardware would already be flight-qualified and might even be Space Transportation System (STS)-qualified.

Moreover, keeping structural changes to a minimum by judicious placement of instruments and instrument appendages on the spacecraft and adding a despun instrument platform would reduce modification costs. Picking a spacecraft in production for several years (as expected through drawing on communication-satellite programs) would likewise radically cut program costs.

We estimate costs for these missions to be $75 million to $150 million.

NASA has asked the Solar System Exploration Committee to verify this picture for a number of missions identified as candidates (T-2), including orbiters, probes, and rendezvous spacecraft to Mars, Venus, the Moon, and nearby asteroids. During the past year, scientific objectives and mission requirements have been developed for all of these missions by SSEC subcommittees in concert with engineers and scientists from NASA-Ames and JPL. The first four missions in T-2 have been extensively studied by private companies under contract ("Phase A" mission studies).

A prime objective of these studies has been to judge whether mission costs can indeed be kept within the "Pioneer"-class by selective scientific objectives and adaptations of Earth orbiters.

The studies also defined the benefits and limitations of this concept. Surprisingly to some, modest

T-2 "PIONEER"-CLASS MISSIONS AND OBJECTIVES

Target body	Mission names	Objectives
Mars	Climatology orbiter	Seasonal volatiles history, climate
Mars	Aeronomy orbiter	Survey upper atmosphere and solar wind interaction, magnetic field
Mars	Geoscience orbiter	Surface composition, magnetic field, topography, gravity
Moon	Geoscience orbiter	Surface composition, topography, gravity
Mars	Penetrator network	Bulk composition, structure, weather
Venus	Atmosphere probe	Atmosphere composition
Near-Earth asteroids	Rendezvous	Composition, density, morphology

T-3 MARS AND MOON ORBITERS

Instruments	Measurement objectives
A. Mars Climatology/Geoscience Orbiter	
Gamma-ray spectrometer	Surface elemental composition; distribution of subsurface ice; thickness of polar caps; composition of polar laminae.
Multispectral mapper	Surface mineral composition; condensed CO_2 and H_2O.
Radar altimeter	Global figure and surface topography.
Atmospheric radiometer	Atmospheric water vapor, dust, condensate clouds, temperatures.
Tracking	Global gravity field and large-scale anomalies.
B. Lunar Geoscience Orbiter	
Gamma-ray spectrometer	Surface elemental composition.
X-ray spectrometer	Polar condensates.
Multispectral mapper	Surface mineral composition, polar condensates.
Radar altimeter	Global figure and surface topography.
Tracking	Global gravity field and large-scale anomalies.

modifications to existing Earth-orbiting spacecraft designs give good results at another planet. Some of the Earth orbiters examined (high-power geosynchronous communication satellites, for example) require only minor internal changes to power, attitude, and communications subsystems. Others need additional changes, such as larger solar arrays, new structure, and new data systems.

The Near-Earth Asteroid Rendezvous mission represents the higher end of the scale. Such missions are exploratory in every sense of the word, since we have not previously visited an asteroid. The first mission would thus have the following fairly comprehensive suite of instruments including moderate-resolution imaging: solid-state imaging, multispectral mapper, γ-ray spectrometer, X-ray spectrometer, magnetometer, and radar. These instruments would determine composition and bulk density, investigate surface morphology, and determine internal properties (including magnetization) of a diverse set of asteroids.

Main-belt asteroids would have first priority, but near-Earth ones would be targets too for both scientific interest and as potential sources of materials for use in space. The main-belt asteroids are more difficult to reach in terms of energy, and lie outside the range of environments (Venus to perhaps 1.8 to 2.0 AU) to which a spacecraft designed for Earth orbit can easily adapt.

The Mars Climatology/Geoscience Orbiter (MCGO) and Lunar Geoscience Orbiter (LGO, see T-2) have a good deal in common. Recognizing this, studies of them have been carried out in a combined manner. T-3 lists candidate instruments and measurement objectives for both.

The data-gathering phase of the two missions would be quite similar. Both would enter low circular polar orbits, allowing all regions of each body to be observed during the mission. The MCGO will go into a slightly retrograde orbit that would receives lower priority than detailed compositional mapping, the goal of MGO and LGO. To keep costs at a modest level it is necessary to keep the goals of the mission tightly focused and not drive the mission or spacecraft design by adding too many requirements on any one mission. Three spacecraft have been considered as candidates for these missions. TRW has studied the adaptability of Fltsatcom, a nadir-pointing geosynchronous communications satellite. RCA has studied the adaptability of both the Dynamics Explorer and the Tiros/DMSP. All appear to be adaptable, although each has virtues and drawbacks.

Fltsatcom, not being a data-gatherer in its original form, requires more modifications in its electronics than the other two. However, it is large and capable and has ample power to perform the mission. Dynamics Explorer is a scientific spacecraft and handles the lunar mission with little change. It needs more solar arrays for Mars, and that requires enlargement of the entire structure of the drum-shaped spacecraft. Tiros has more capability than really required.

Thus the results of studies made to date encourage us to believe that advantage can be taken of the large investments made by the aerospace industry for missions in the inner solar system.

Exploring the Moon and Mars with Earth Orbiters

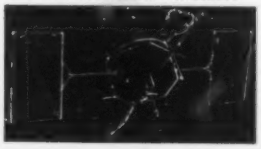
The Mars Geoscience Orbiter (MGO) is being considered for an FY85 start with a launch in July of 1986. The lunar mission is more flexible as to launch opportunity but would probably go at roughly the same time.

As noted in the article, the MGO and LGO missions are very similar. The difference in payload is that the LGO can carry an X-ray spectrometer; MGO does not since X-rays are absorbed by the planet's atmosphere. A radar altimeter provides a precise measurement of the global topography and tracking data and adds to knowledge of the global gravity field for both the Moon and Mars. Mineralogical data will be generated by a multispectral mapper for both.

By the addition of an atmospheric radiometer and optional ultraviolet instruments, the MGO can acquire a body of data that will yield better understanding of the past and present behavior of volatiles on Mars.

Conspicuous by its absence on both MGO and LGO is an imaging system. Unlike the asteroid mission, which requires imaging because we have never seen an asteroid in space (and also because of spacecraft guidance requirements at rendezvous), the Moon and Mars have already been mapped at optical wavelengths. Further high-resolution imaging thus

FLTSATCOM-BASED PLANETARY SPACECRAFT

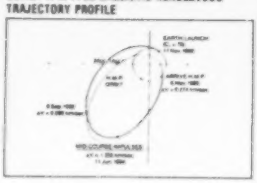


Rendezvous with HMP

Comet exploration deserves a high priority because comets may be the only obtainable source of the primitive material from which the solar system was formed. A rendezvousing spacecraft should observe a comet for several months at close range as its acticity builds up and dies down to map the physical and chemical properties of the nucleus.

Comet Honda-Mrkos-Pajdusakova makes a good candidate for a comet rendezvous mission. HMP is one of the brightest short-period comets. It has an orbital period of 5.3 yr and has been observed through six perihelion passages since its discovery. It exhibits both a well developed coma and an ion tail for 20 days before and after its closest approach to the Sun. The viewing geometry from Earth will be exceptionally favorable during HMP's perihelion passage in December 1995.

COMET H-M-P/95 BALLISTIC RENDEZVOUS TRAJECTORY PROFILE



Thus a 1995 rendezvous with HMP has been included in the Mariner Mark II study. The spacecraft would be launched by the Centaur stage from the Space Shuttle in November 1990. After two interplanetary propulsion maneuvers, it would rendezvous with the comet in November 1995, fifty days before perihelion passage. The post-rendezvous exploration might begin with a few close passes of the nucleus followed by retreat to a safe distance of perhaps 5000 km when the comet is most active. Once the dust hazard has subsided, after perihelion, the spacecraft would explore the comet's atmosphere and make progressively closer passes of the nucleus down to a 10-km mapping orbit. The mission might end with a touchdown on the nucleus.

precess in such a way as to maintain a constant angle between the orbit plane and the Sun-planet line. This provides optimum observations for multispectral-mapper and climatology experiments. Such an orbit would be desirable for the Moon as well but is not possible. The spacecraft operate in the final observation orbits for at least one Earth year to obtain enough γ-ray spectrometer data for accurate analysis. An extension to the mission is possible and probably desirable to study seasonal variation.

The major changes in the spacecraft, other than the payload differences noted, concern telecommunications systems and the orbit-insertion propulsion system. The much shorter communications range from the Moon allows an antenna of lower gain. Similarly, the propulsion requirements for the Moon are lower.

MCGO and LGO similarities suggest a single program to do both. Preliminary estimates indicate that both missions could be done for less than 150% of the cost of MCGO alone. Even more tantalizing is the possibility that both could be launched from the same Shuttle flight by the simple expedient of waiting in orbit for a few days between launches.

MCGO and LGO will operate roughly in the manner of an Earth-orbiting weather satellite. One listen-only station pass each day would broadcast that day's data to the DSN. Once a week a two-way link would be established to update the onboard computer and to provide data for orbit prediction. Otherwise the spacecraft would operate without ground intervention. Such practice will greatly reduce the cost of operations compared to previous, more adaptive missions.

Spacecraft would be modest in size and weight as well as in costs. Most payloads would occupy 6 m of Shuttle payload-bay length and weigh about 12,000 kg—take only a third of the payload-bay length and less than half of payload weight capacity, leaving the balance for other payloads.

All results from Phase A studies indicate that—

—Several types of Earth-orbiting spacecraft can be modified for conducting "Pioneer"-class missions at modest cost.

—Scientific objectives need not be compromised.

Members of the science community have reviewed this concept and these study results and have voiced support for such missions as a practical means of conducting useful science in these difficult financial times.

The Mariner Mark II (MMII) Concept: For certain deep-space missions, the third approach envisions developing both a spacecraft design which can be reconfigured at low cost from mission to mission and a design for a ground-support system that could be used for all the missions without reconfiguration. Design concepts draw heavily on earlier planetary missions but also include new technology expected to be available in the late '80s and the '90s. Modular subsystem design standards would support ready reconfiguration for various missions. The approach has been named Mariner Mark II. It encompasses the following types of missions:

- *Comet rendezvous.* Although the 1986 flybys of Halley will address many important questions about comets, a thorough investigation requires a rendezvous mission with a much longer period of observation at closer range. The choice of targets for a comet rendezvous is limited to short-period comets in low-inclination orbits.
- *Comet-sample return.* It is possible to sweep up

cometary gas and dust with a spacecraft that passes through a comet's atmosphere at high velocity and then to return that sample to Earth for analysis. Studying a single comet by simultaneous rendezvous and sample return would improve scientific study.

- *Main-belt asteroid tours.* A Mars gravity assist could send a spacecraft into the asteroid belt. Once there, a single spacecraft can rendezvous with two asteroids in succession or combine a rendezvous of one asteroid with flybys of several others.
- *Saturn orbiter.* A spacecraft in orbit around Saturn can use close flybys of the satellite Titan to adjust its trajectory to achieve a wide variety of orbits. Successive orbits can be used for close flybys of different satellites or for ring or magnetosphere studies.
- *Probe carriers.* An MMII spacecraft might also deliver probes to Titan, Saturn, Uranus, or Neptune. The probes would be the same as those described earlier, but the MMII carrier would allow more sophisticated mapping at visible, infrared, or radar wavelengths.
- *Mars orbiter.* Although the requirements for a Mars orbiter do not drive the MMII design, MMII could execute an excellent Mars geochemical mapping and climate studies mission.

To carry out such missions, the MMII spacecraft must be launchable by either a Shuttle IUS or a Shuttle Centaur. It must have a post-launch propulsion capability of up to 3 km/sec (up to 4 km/sec for some main-belt asteroid tours), operate for periods of up to 8 yr (10-12 yr if a Neptune mission is included in the set), communicate over distances as great as 11 AU (30 AU for Neptune), and operate over a range of solar distances from 1 to 10 AU (0.34 AU if the comet mission is an Encke rendezvous and up to 30 AU for a Neptune mission). Both the onboard optical navigation required for some missions and the scientific observations argue a three-axis stabilized platform with a pointing accuracy of 2 mrad. Data rates of 10-30 kbps are required, as is on-board data storage.

F-3 illustrates the modular, reconfigurable spacecraft design being considered for MMII. The central module supports the external modules and houses the spacecraft electronics and other assemblies that do not require external mounting.

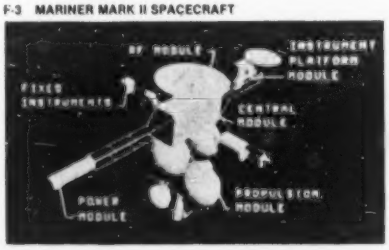
The radio-frequency (RF) module includes a body-fixed high-gain antenna together with its feed and receiver. The antenna size can be changed from mission to mission.

The power module would accomodate either a radioisotope thermoelectric generator (RTG) or a solar panel. An RTG is the power source of choice for the outer-planet missions, which must operate at great distances from the Sun. However, because an RTG is a source of radioactivity, it cannot be used on spacecraft that carry gamma-ray spectrometers for measuring the composition of the target body by analysis of the low-level flux of gamma rays which it emits naturally. For such missions, the power source would be a solar panel.

The propulsion module provides both the impulse for trajectory changes (ΔV) and the reaction control required for maintaining the proper orientation of the spacecraft. (F-3 shows the number of tanks corresponding to a $\Delta V = 2.9$ km/sec required for a comet rendezvous.)

The scientific instruments and attitude-control

F-3 MARINER MARK II SPACECRAFT



sensors are located either on the outside of the central module, on fixed booms, or on an articulated platform. This platform can rotate about either of two axes to allow the sensors on it to be pointed in almost any direction to view either reference stars or the target body. The final module (not shown in F-3) would be a probe or the Earth-return capsule for the comet sample-return mission.

F-4 illustrates how the spacecraft could be reconfigured from one mission to the next. F-4a could be used as a Saturn orbiter. F-4b shows a similar Mars orbiter, but having a solar panel rather than an RTG power source. The comet- and asteroid-rendezvous spacecraft would look like either 4a or 4b, depending on whether or not a gamma-ray spectrometer was part of the payload and how far from the Sun the spacecraft must operate. F-4c shows how the spacecraft might be configured for a probe-carrying mission. The propellant tanks required for interplanetary maneuvers would be jettisoned before the probe was released. The comet sample return spacecraft (F-4d) would be protected during its high-speed flight through the cometary dust cloud by a structure serving both as a bumper shield and sample collector. During flyby,

the power module and the scan platform would be folded back and hidden behind the shield.

The present concept assumes that the following new technology will be developed in time for use on MMII—

—A communications system which uses X-band frequencies on both the uplink and downlink.

—A bus-based data system with bus-interface modules to be placed in each subsystem or instrument to allow flexibility without changes to the data system.

—Fiber-optic rotation sensors (replacing conventional gyrosopes).

—A CCD-based star tracker that can image a field of stars or can be used in a closed-loop mode as a target-body tracker.

For a set of four or five missions in a decade, MMII costs should run between $175 and $325 million per mission (in FY83 dollars), *with an average spending rate of $100 million or less.*

Planetary missions, by definition, require Earth-escape launch power. That almost always exceeds the impulse requirements of Earth-orbital missions. Using the initial deployment impulse of geosynchronous missions as a basis of comparison, planetary departure impulses run some 30% higher for lunar missions, 50-75% higher for inner-planet missions, 75-100% higher for small-body missions, and possibly more than 200% higher for outer-planet missions. These launch requirements have always kept planetary missions at the forefront of launch-vehicle development issues.

Obviously, even our best efforts at reducing mission cost will not revive the solar-system exploration program if we do not have adequate launchers. On the other hand, we need to appraise realistically the pace at which NASA's STS can progress to meet planetary-mission requirements.

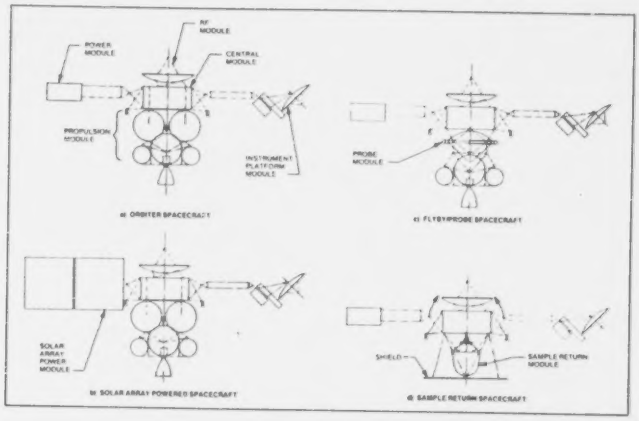
Upper stage requirements of the evolving new approaches can be briefly summarized as follows. The Pioneer-class missions using existing Earth-orbital hardware for inner-planet exploration will require less than IUS two-stage capability. Solid motors, such as the PAM-A and the large IUS motor, are attractive upper-stage candidates for these spacecraft. Additionally, payload-bay requirements are small enough that the Shuttle launch costs can be shared with a second mission. The remainder of the lower-cost approaches (e.g., Venus Radar Mapper, comet rendezvous, main-belt multi-asteroid rendezvous, outer-planet probe missions, and a Saturn orbiter) under consideration by the SSEC could, if necessary, be performed with the IUS two-stage plus a solid kick-stage motor.

Using the IUS two-stage for these projects may not, however, be the most cost-effective means. Many would then need indirect ΔVEGA transfers and infrequent planetary swingbys. The added cost of thus extending trip times and the inability to adjust flight schedules to a unique swingby requirement could easily off-set any cost advantage associated with basing MMII and outer-planet probe missions on the IUS two-stage.

Development of a Shuttle Centaur upper stage

(Continued on page 52)

F-4 MARINER MARK II CONFIGURATIONS



(Continued from page 38)

greatly improves the SSEC's ability to formulate an effective low-cost exploration program. Planning consequences include more comets from which to select a rendezvous mission, more asteroid-rendezvous targets per mission, more outer-planet launch opportunities, shorter trip times, and the possibility of dual-payload launches.

These advantages expand the scope of exploration, improve mission scheduling, and reduce operational costs. The SSEC has endorsed the development of a Solar Electric Propulsion Stage (SEPS) for similar reasons. Although a new direction in planetary exploration can be initiated without SEPS, the longer-term need for it persists. Certain comets and asteroid-sample returns, outer-planet satellite missions, and Mercury orbiters require the SEPS performance.

It is expected that the approaches to lowering the cost of planetary missions described here will be a central part of the program on missions recommended by the SSEC at the completion of its October 1982 study. The committee has also noted that opportunities to lower NASA mission costs, and to reap other benefits, are presented by planetary missions undertaken in cooperation with other nations.

Recommendations from the study will complete the first phase of the SSEC's activity. It will then take on a somewhat different character.

Emphasis to date in the SSEC's considerations has been set by economic conditions in our country and the near-term goals of NASA. Looking further ahead and presuming that the nation's economy will recover, space science should flourish again, leading to a need for a vigorous planetary program rather than one that is highly constrained. The content of such a program might include Mars missions of the Viking class (e.g., sample return and mobile laboratories) and precursor missions for a lunar base. Other missions of interest in an expansive planetary program include intensive study of the Earth-approaching asteroids in anticipation of their exploitation as resources and, as a new area of scientific investigation, Earth-orbital facilities to search for planetary systems about other stars.

When the nation's economic position permits, the more challenging missions could augment the "core" program recommended by the SSEC and return the planetary-exploration program to its former expansiveness.

Acknowledgements

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A Program for Planetary Exploration

David Morrison and Noel W. Hinners

Summary. On the basis of a two-year study, the NASA Solar System Exploration Committee recommends a core program of planetary missions through the year 2000. By incorporating a number of cost-saving measures, an exciting program of planetary exploration can be achieved within a highly constrained NASA budget.

During the 20 years from the first Mariner flyby of Venus to the Voyager 2 encounter with Saturn, planetary exploration experienced its golden age. More than 40 robot spacecraft probed first toward the moon, Venus, and Mars, then ultimately to every planet known to ancient peoples, from Mercury to Saturn. Most of these spacecraft were launched by the United States, bearing names symbolic of their exploratory missions: Ranger, Surveyor, Pioneer, Mariner, Viking, and Voyager. The Soviet Union, the other nation to contribute to this era of discovery, focused its efforts more narrowly on the moon and Venus, but it too achieved remarkable successes. Within less than a generation, there was a revolution in our understanding of the solar system.

After such a brilliant beginning, it is natural to ask, What next? What new worlds remain to be explored? How do we best capitalize on our past successes? And perhaps most important in a time of constrained budgets, how do we justify continuing planetary exploration in the face of so many other worthy programs competing for federal research dollars?

As the 1970's drew to a close, planetary scientists asked these questions with increasing urgency. Following the 1977 approval for development of a Galileo orbiter and probe to Jupiter, there was increasing resistance to proposals for further initiatives in planetary exploration. Galileo was postponed repeatedly by launch vehicle delays, and its status remained precarious until the decision last August to adapt the powerful Centaur upper stage for the Shuttle (*1*). Meanwhile, the funds available to NASA for planetary exploration have dropped to 20 percent of their mid-1970's peak (*2*), and even the excitement of the Voyager encounters with Jupiter and Saturn and the once-in-a-lifetime opportunity to send a spacecraft to Comet Halley in 1986 (*3*) failed to reverse the declining support for planetary science.

The need for a fresh look at planetary priorities prompted the NASA administrator in late 1980 to appoint a special committee of the NASA Advisory Council to recommend an implementation strategy for planetary missions through the year 2000. This Solar System Exploration Committee (SSEC) (*4*) has now completed the first part of its task with the publication of a recommended core program of low- and moderate-priced missions. The program is intended to establish a stable basis for planetary science, so that scientifically exciting missions can be carried out within a framework of cost-saving engineering and management approaches. We report here the most important elements of this core program (*5*).

David Morrison is a professor of astronomy at the University of Hawaii, Honolulu 96822, past chairman of the Division for Planetary Science of the American Astronomical Society, and chairman of the NASA Solar System Exploration Committee. Noel W. Hinners, the committee's past chairman, is director of NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, and president of the Planetology Section of the American Geophysical Union.

The Basis for Planetary Exploration

Planetary science is a relatively young discipline which has flourished in the United States primarily in response to the development of a deep space launch capability. Before the space age, planetary research was largely the province of a handful of astronomers, such as those working with Gerard P. Kuiper at the University of Chicago, while in the geosciences a few workers, notably Harold C. Urey, had begun to look at the meteorites as an important potential source of information on the formation of the solar system. Today, planetary science has more than a thousand full-time participants (*6*), drawn from backgrounds in physics, astronomy, meteorology, meteoritics, geology, geophysics, and geochemistry, and is supported by tens of millions of dollars in federal funds. Drawing on this multidisciplinary background and spacecraft data of unprecedented quantity and quality, planetary science has achieved a new perspective in the way we view our own planet. From the complex atmospheric chemistry of Venus to the evidence for climatic change on Mars, from the sulfur volcanoes of Io to the spiral density waves propagating through the rings of Saturn, from the superheated plasma of the Jovian magnetosphere to the isotopic imprint of supernova nucleosynthesis in the Allende meteorite, planetary perspectives now pervade our approach to a wide variety of problems in physics, astronomy, and the geosciences.

The fundamental goals of scientific exploration of the solar system have been (i) to determine the present state, origin, and evolution of the solar system, (ii) to better understand the Earth by comparative studies, and (iii) to improve our understanding of the relation between the appearance of life and the chemical history of the solar system. In the case of the moon, the Ranger, Sur-

veyor, and Lunar Orbiter missions also provided critical support to the manned Apollo Program, and in the future the need to assess resources for utilization by an increasing human presence in space may become an important supporting objective of planetary exploration (*7*).

To translate these general goals into a plan of action, we may consider a matrix. Along one dimension lie the diverse objects within the solar system: (i) the inner or terrestrial planets; (ii) the outer or Jovian planets, with their rings and satellite systems; and (iii) the comets and asteroids, chemically primitive debris surviving from the origin of the solar system. The second coordinate of the matrix is a measure of our level of knowledge. This knowledge has progressed, through a series of missions of increasing technological sophistication, from flyby reconnaissance spacecraft to orbiters, entry probes or landers, and ultimately return of samples for terrestrial analysis. Our progress in filling in this matrix has been uneven. We have been most successful in the inner solar system, reaching the level of landers on Venus and Mars and of sample return from the moon. In the outer solar system, we have accomplished flybys of Jupiter and Saturn, and in 1988 Galileo will provide an orbiter and entry probe for Jupiter. No missions have yet been launched to the small, primitive bodies, although several non-U.S. flyby missions are planned for Comet Halley when it approaches the sun three years from now (*3*).

Excluding the special case of the moon, the United States has launched 17 successful planetary spacecraft, including two Viking Mars landers and a group of Pioneer Venus atmospheric entry probes (Table 1). The U.S.S.R. has achieved success with 11 Venera missions to Venus, including seven landers. These missions have demonstrated our ability to apply the most advanced technology to important and challenging tasks outside the national security arena. But the pictures returned by a Viking or Voyager can also distort our perspective, because our approach to planetary exploration is the reverse of that used over centuries in the exploration of Earth. From space, we begin with a global view of another planet and only later move to detailed observations and measurements in selected regions. This has proved to be a powerful approach, but only because scientists have been able to extrapolate from their knowledge of basic processes learned on Earth. It generates an immediate global perspective, even from a first mission, but also tends to create an overly optimistic impression of the state of our knowledge. Experience has shown that many interpretations based on data from first-generation reconnaissance missions require substantial revision when more capable spacecraft arrive later (*8*). The importance of following up on our early discoveries cannot be overemphasized if we desire a true understanding of other planets and the processes that mold them.

A critical appraisal of where we stand today in planetary science also reveals large parts of the solar system where we have not even begun to explore. The entire surface of Venus and half that of Mercury remain terra incognita (*9*). No spacecraft has yet visited Uranus, Neptune, or Pluto (*10*), and we have only flyby data on Jupiter, Saturn, and their ring and satellite systems. We have yet to send a spacecraft to a comet or asteroid. These small, volatile-rich messengers from the distant past have not experienced the large-scale chemical and physical modification that has affected the larger planets and satellites, and they promise especially rewarding insights into the earliest history of the solar system.

Table 1. NASA planetary missions (not including lunar flights).

Spacecraft	Launch date	Destination	Encounter date	Type of encounter
Mariner 2	26 August 1962	Venus	14 December 1962	Flyby
Mariner 4	28 November 1964	Mars	14 July 1965	Flyby
Mariner 5	14 June 1967	Venus	19 October 1967	Flyby
Mariner 6	25 February 1969	Mars	31 July 1969	Flyby
Mariner 7	27 March 1969	Mars	5 August 1969	Flyby
Mariner 9	30 May 1971	Mars	13 November 1971	Orbiter
Pioneer 10	3 March 1972	Jupiter	4 December 1973	Flyby
Pioneer 11	6 April 1973	Jupiter	3 December 1974	Flyby
		Saturn	1 September 1979	Flyby
Mariner 10	3 November 1973	Venus	5 February 1974	Flyby
		Mercury	29 March 1974	Flyby
Viking 1	20 August 1975	Mars	19 June 1976	Orbiter
			20 July 1976	Lander
Viking 2	9 September 1975	Mars	7 July 1976	Orbiter
			3 September 1976	Lander
Voyager 1	5 September 1977	Jupiter	5 March 1979	Flyby
		Saturn	12 November 1980	Flyby
Voyager 2	20 August 1977	Jupiter	9 July 1979	Flyby
		Saturn	25 August 1981	Flyby
		Uranus?	1986	Flyby
		Neptune?	1989	Flyby
Pioneer Venus	20 May 1978	Venus	4 December 1978	Orbiter
	8 August 1978	Venus	9 December 1978	Probes
Galileo?	1986	Jupiter	1988	Orbiter
		Jupiter	1988	Probe

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Recommendations by the Space Science Board

In formulating a mission strategy, the SSEC has depended on scientific priorities for space science articulated by the National Academy of Sciences through its Space Science Board. Created in 1958, the Space Science Board has advised NASA throughout its history on overall scientific priorities (*11*). During the past several years, specific recommendations in planetary science have been developed by the Board's Committee on Planetary and Lunar Exploration (COMPLEX) and published in three reports (*12*). These reports are viewed as being of equal priority in shaping the scientific basis for the planetary exploration program.

For the inner planets, COMPLEX recommended a major focus on studies of the triad Venus, Earth, and Mars. These terrestrial planets, which are roughly similar in size, location, and composition, have followed strikingly different evolutionary tracks, and comparative studies should lead to a profound advance in knowledge, particularly with respect to our own planet. COMPLEX emphasized the gap in our knowledge represented by the unknown surface of Venus, and it accorded highest priority to the acquisition of a surface map with a resolution of ~ 1 kilometer.

The comets and asteroids represent the major planetary area in which spacecraft studies have not yet been initiated, and COMPLEX emphasized the urgency of beginning their study in order to probe the earliest periods of solar system history. Exploratory missions should sam-

ple the diversity of both comets and asteroids, as well as measure a few objects in detail.

Outer solar system studies are the one area of the planetary program that has retained a fair degree of momentum, with the forthcoming Voyager 2 flybys of Uranus and Neptune and development of the Galileo mission for a 1986 launch to Jupiter. For the next step, COMPLEX endorsed in-depth study of the Saturn system from an orbiter and a follow-up to the Voyager discoveries for Saturn's cloud-shrouded satellite Titan.

While COMPLEX and the Space Science Board have established the scientific objectives for future planetary exploration, they have not addressed the specific means by which these objectives should be accomplished. The development of a mission plan, with appropriate attention to technological and fiscal constraints, is the task of the SSEC.

Technological Considerations

Choice of missions has always depended in part on technological capability, and improvements in technology have led to more ambitious missions of increasing complexity, such as Viking, Voyager, and Galileo. In a period of budgetary constraint, it could be argued that the planetary community was pricing itself out of the market (*13*). Further, a cycle was developing in which the long intervals between flights decreased the opportunities for cost-saving use of hardware and designs from previous missions ("inheritance"), while increasing the pressure to include the maximum science payload in each flight. One of the first priorities of the SSEC was to break this cycle, increasing the opportunities for new missions by reducing their individual costs and phasing them together more efficiently (Fig. 1).

A first step was to identify the key elements that drive mission costs. There are three primary factors: (i) the degree of hardware and software design inheritance from mission to mission, (ii) the scientific scope and hence complexity of any given mission, and (iii) the degree of change that occurs after the mission is approved. The first two of these factors appear to be reinforcing, as noted above. The SSEC decided to limit its recommendations for a core program to missions that are restrained and focused in scope and where high inheritance can be achieved (*14*).

The missions in the core program must be insulated as far as possible from costly changes and delays once they are approved. In the past, many such changes have been outside the control of planetary program management, as in the delays and redirection in Galileo that arose from repeated launch vehicle changes. To avoid such costly problems, the SSEC has restricted its recommendations to missions that do not require new enabling technologies, such as specially designed upper stages, low-thrust propulsion systems, mobile landers, or sample return capabilities. Instead, it recommends vigorous utilization of the basic mission types that have been successful in the past: flybys, orbiters, and atmospheric entry probes. Such an approach promises a maximum scientific return on investment and a minimum probability of costly and disruptive delays.

Essential to the realization of the mission plan is the availability of the high-performance Centaur upper stage for the Shuttle. The Shuttle/Centaur brings within reach a number of missions, including comet and asteroid rendezvous, that were once thought to require such new technologies as low-thrust propulsion. Many missions in the core program require Shuttle/Centaur, but none demand more performance than will be provided by this combination (*15*).

Additional savings can be achieved in spacecraft design. For the inner solar system, the SSEC recommends the modification of spacecraft developed by aerospace companies for a variety of commercial applications in Earth orbit (*16*). Although there are few true production lines for spacecraft, the production rates within this industry are such that the costs of high-capability spacecraft are modest compared with those of the specialized spacecraft generally used for planetary exploration. Such spacecraft are limited to the inner solar system, however, since their thermal control, power, and communications systems would generally prove inadequate for more distant operations.

For exploration of the small bodies and the outer planets, the most efficient approach is to develop a modular spacecraft free of unnecessary complexity and designed for maximum inheritance and ease of reconfigurability. If the mass of this spacecraft (excluding fuel) can be held below 600 kilograms, a number of missions are possible that cannot be achieved with the larger Galileo-class vehicles. This new spacecraft, which would be similar in power, guidance, pointing, and communications capabilities to the Mariners and Voyagers, has been informally termed the Mariner Mark II. Its design, including the development of an integrated ground support system, is under way at Jet Propulsion Laboratory (*17*).

Additional efficiency for probe missions to the outer planets can be achieved by taking advantage of the highly capable Galileo entry probe. The Jovian entry problem will be the most demanding one; having solved it, we can use the same probe design for Saturn, Uranus, Neptune, and Titan. For these missions, the Mariner Mark II could serve as a probe carrier.

The use of derivatives of commercial Earth satellites for inner planet missions and of the Mariner Mark II for missions beyond Mars should lead to significant savings in both mission development and operations. Efficiency will be increased in both cases if the science objectives for each mission are carefully controlled and the frequency of launches is high. These approaches provide the key to carrying out planetary exploration within a constrained budget.

Proposed Missions for the Core Program

Consistent with its conviction that our understanding of the solar system is best served by a balanced exploration program, the committee recommends missions in all three major areas: inner planets, small bodies, and outer planets. For the core program discussed here, only modestly priced missions that do not require new enabling technology are proposed (see Table 2).

Inner planets. A principal scientific objective of inner solar system exploration is to understand the nature and evolution of the interiors, surfaces, and atmospheres of Earth, Venus, and Mars. It has been apparent for some time that the single largest gap in our data base for these planets is our ignorance of the geology of Venus. While the Pioneer Venus Orbiter was able to produce a global altimetry map with a maximum horizontal resolution of 50 to 75 km (*18*), there is virtually no information on the surface topography on scales that might reveal most geological processes and history. The SSEC assigns its highest mission priority to a Venus Radar Mapper (VRM), which will provide a global reconnaissance of the surface equivalent to that carried out by cameras on the first Mars orbiter, Mariner 9 (*19*). The objectives of this mission are to (i) obtain a near-global map by using synthetic aperture radar with subkilometer resolution, (ii) provide global and local topographic

Table 2. Missions in the SSEC core program. These are not listed in order of priority, except as noted in the text.

Inner planets	Small bodies	Outer planets
Venus Radar Mapper	Comet Rendezvous	Titan Probe/Radar Mapper
Mars Geoscience/Climatology Orbiter	Comet Atomized Sample Return	Saturn Orbiter
Mars Aeronomy Orbiter	Main Belt Multiasteroid Orbiter/Flyby	Saturn Probe
Mars Surface Probe	Near-Earth Asteroid Rendezvous	Uranus Probe
Lunar Geoscience Orbiter		
Venus Atmospheric Probe		

information with a radar altimeter, and (iii) extend the global gravity field measurements obtained by Pioneer Venus. This mission is proposed for launch in 1988 and will complete its primary phase after 243 days in Venus orbit (*20*).

The VRM mission has been derived from studies of a more complicated, twice as expensive mission, the Venus Orbiting Imaging Radar (VOIR) (*21*). As presently conceived, it capitalizes on a number of the cost-saving measures, including (i) limited science objectives (focused on radar mapping, to the exclusion of various atmospheric studies planned for VOIR), (ii) high hardware inheritance (for instance, use of a spare Voyager antenna for both the radar mapper and Earth communications), and (iii) use of new technology to reduce costs (advances in synthetic aperture radar allow imaging from an elliptical orbit, providing major cost and weight savings relative to the low circular orbit planned for VOIR).

The highest priority scientific objectives for Mars require the return of a surface sample to Earth and therefore lie outside the boundaries of the core program. However, many objectives that are basic to understanding Mars are attainable within the SSEC guidelines. These include studies of surface composition and mineralogy, of the distribution and atmospheric transport of volatiles, of global atmospheric dynamics, and of the structure and photochemistry of the upper atmosphere. All these investigations, which would produce major advances over the limited measurements made by the two Viking orbiters, can be carried out with relatively simple spacecraft derived from commercial Earth satellites.

The SSEC recommends early initiation of a Mars orbiter, emphasizing investigation of the geology and climate of the planet. The Mars Geoscience/Climatology Orbiter, the first of the new class of low-cost inner planet missions, should be launched in 1990 into a 300-km polar orbit, where it would operate for one Mars year. Its objectives are to obtain global maps of elemental and mineralogical surface composition and of the planet's figure and surface topography, to deduce the nature of the magnetic field (if any), to measure the seasonal cycles of carbon dioxide, water, and dust, and to study the interactions between volatile reservoirs (such as the polar caps) and the atmosphere. High-resolution imaging is not a part of this mission. The Viking orbiters have already given us excellent maps of Mars, and our greatest scientific need now is for quantitative data of the type discussed for this mission.

If humans are to consider the establishment of a permanent and self-sufficient presence in space, we must learn more about our nearest neighbors, the moon and the near-Earth asteroids. The same spacecraft and instruments used to map the figure, surface topography, and composition of Mars can also be used to carry out similar studies of the moon from polar orbit (*22*). The SSEC recommends that a Lunar Geoscience Orbiter be included as a follow-up to the Mars orbiter to realize the maximum savings from hardware inheritance and joint mission operations. A similar early opportunity exists to send a geochemical spacecraft, supplemented by imaging cameras, to rendezvous with an Earth-approaching asteroid and initiate our exploration of this new class of objects (*23*).

Other inner planet missions in the SSEC core program are a Venus Atmospheric Probe, a Mars Aeronomy Orbiter, and Mars hard landers or penetrators. These are all missions to be initiated in the 1990's, and it is hoped that one or more of them might be carried out by other nations, either independently or in collaboration with NASA.

Small bodies. Comets and asteroids compensate for their diminutive size by their large numbers and by the extraordinary interest they hold as chemically primitive objects, little modified since their presumed formation 4.6×10^9 years ago. The diverse populations of comets and asteroids have been much studied by telescope in recent years (*24*), but no mission has been launched to any of these objects, in spite of studies and recommendations that go back to the early days of NASA (*25*). To maintain a balanced perspective on the planetary system and particularly to probe the conditions of its birth and early evolution, the SSEC concurs with COMPLEX and other advisory bodies in recommending early initiation of missions to comets and asteroids.

An essential element of comets and asteroids is their diversity. No one object holds the key to either class. However, there is sufficient information about the characteristics of the major classes of comets and asteroids to permit an intelligent selection of targets, while the Shuttle/Centaur has the capability to launch spacecraft that can visit more than one target in a single mission. Thus we are technologically and scientifically poised to begin the direct exploration of these smaller worlds.

Following the fast flybys of Comet Halley in 1986, the next step in cometary exploration should be a rendezvous mission with a short-period comet. The spacecraft would match orbit with its target many weeks before perihelion and follow it through its activity cycle as it is heated by sunlight and then recedes again into deep space. Among the accessible short-period comets, three suitable targets have been identified: Encke, Tempel 2, and Honda-Mrkos-Pajdusakova (HMP). Each has a period of less than ten years, and each has suitable apparitions during the late 1980's and the 1990's (*26*). The spacecraft would carry cameras and other remote sensing instruments (similar to those on Voyager or Galileo) in addition to direct sensing instruments to study the gas and dust in the cometary atmosphere. Comet HMP presents one of the first opportunities for a rendezvous, with a 1990 launch, 1994 arrival, and 1995 perihelion. En route to its primary target, the spacecraft would fly by a main-belt asteroid, initiating a study of this class of objects. A comet rendezvous is the first Mariner Mark II mission in the core program.

Complementing a rendezvous is the acquisition and return to Earth of a sample of cometary material. It is usually assumed that sample returns can be attempted only after a sequence of reconnaissance and exploration missions. For comets, however, a novel kind of sample return can be carried out even within the restrictions of the SSEC core program. A simple fast-flyby spacecraft can acquire an atomized sample return of dust particles that are vaporized by impact on a foil diaphragm and recondense on the walls of a collection cell, which is returned to Earth for laboratory analysis.

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In this way, a detailed analysis of the elemental and isotopic composition of the nonvolatile component of cometary dust can be carried out. For Comet HMP, a 1994 launch would yield an encounter in 1995 and a return to Earth in 1996 (*27*).

For initial exploration of the asteroids, the SSEC recommends a Main Belt Multiasteroid Orbiter/Flyby Mission. A combination of flybys and orbiters is required to achieve the necessary depth and breadth, but these functions can be combined in a single Mariner Mark II spacecraft with Shuttle/Centaur launch (*28*). The objectives are Voyager-class imaging and remote sensing studies of several asteroids en route to (or following) a 60- to 90-day orbit of the primary target. During orbit, more detailed elemental and mineralogical analysis of the asteroid surface can be carried out. One mission studied for a 1992 launch would have as its primary target asteroid 4 Vesta, one of the largest and most interesting main-belt objects (*29*), with additional flybys of 313 Chaldaea and 101 Helena, two objects of differing compositional type with diameters of 120 and 70 km. In general, opportunities for good main-belt asteroid missions recur at two-year intervals throughout the 1990's.

Outer planets. In the giant outer planets and their systems of rings and satellites are found more than 99 percent of the planetary system's mass, 45 of the 48 known satellites, the only ring systems, and (in the case of Jupiter and Saturn) magnetospheres that are vastly larger and more complex than those associated with the inner planets. During the rest of this decade, Voyager 2 will continue its mission to Uranus and Neptune, while Galileo will provide a much more detailed investigation of the Jupiter system. The next step, beyond Voyager and Galileo, will be the in-depth exploration of the Saturn system, especially its largest satellite, Titan.

The SSEC's first priority mission to the outer solar system is a Titan Probe/Radar Mapper, ideally to be carried out in conjunction with a Saturn Orbiter. Titan is unique, having an evolved reducing atmosphere that contains more nitrogen than our own, in addition to methane, carbon monoxide, and more complex organic compounds. The surface of Titan is cold enough for methane to condense, possibly forming pools or oceans. A Titan probe could be a modification of the Galileo Jupiter probe, with an instrumented package to sound and sample the atmosphere as it descends by parachute to the surface. At the same time, radar on the probe carrier could provide an image of part of the cloud-shrouded surface at a resolution of a few kilometers.

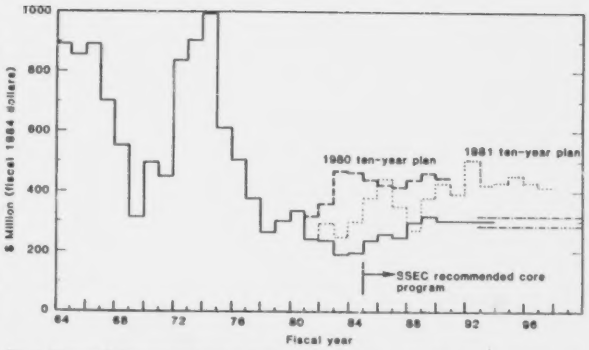

Fig. 1. History of planetary exploration funding: annual budgets of NASA's Planetary Division since FY 1964, expressed in constant value (FY 1984) dollars. Three future projections are shown: the NASA ten-year plan of 1980, the NASA ten-year plan of 1981, and the SSEC core program of 1983. Note that the annual expenditures in the SSEC core program are one-third the high levels of funding of the middle 1960's and 1970's.

If the Titan probe carrier is a full-scale Saturn Orbiter, a mission analogous to Galileo could be carried out in the Saturn system, with detailed study of the atmosphere, magnetosphere, satellites, and rings. Launches can be accomplished every 13 months, with a flight time of six to eight years (*30*). A combined Titan Probe and Saturn Orbiter has been considered an excellent candidate for international cooperation.

The other outer planet missions in the SSEC core program are atmospheric probes based on the Galileo probe design. The objective of these missions is the direct comparative study of the atmospheres of Saturn, Uranus, and Neptune with instruments similar to those being sent to Jupiter. The probe carriers could be instrumented for flyby remote sensing more advanced than that of Voyager; such a capability would also provide a backup in case Voyager 2 fails before it completes the initial reconnaissance of the outer two giant planets (*31*).

Mission summary. The recommended core program includes 14 missions, to be launched between 1988 and 2000. The first four missions in this sequence have been analyzed in some detail and can be firmly recommended at this time. These are (i) the Venus Radar Mapper (1988 launch), (ii) the Mars Geoscience/Climatology Orbiter (1990 launch), (iii) the Comet Rendezvous with Asteroid Flyby (1990 launch), and (iv) the Titan Probe/Radar Mapper. The Titan mission would probably be launched in the early 1990's, but international cooperation could result in an earlier mission, perhaps in conjunction with a Saturn Orbiter.

The sequence of other missions in the core program will be determined by programmatic issues that cannot be foreseen at this time. Major considerations in their execution should include the need to maintain scientific balance and the desire to realize maximum efficiencies in cost and utilization of manpower. These additional missions are, in no order of priority: Mars Aeronomy Orbiter, Venus Atmospheric Probe, Lunar Geoscience Orbiter, Mars Surface Probe, Near-Earth Asteroid Rendezvous, Main-Belt Multiasteroid Orbiter/Flyby, Comet Atomized Sample Return, Saturn Probe, Uranus Probe, and Saturn Orbiter. The SSEC recommends that all of these moderate-cost missions be undertaken between now and the year 2000, by the United States alone or in collaboration with other nations (*32*).

Costs of the Core Missions

In developing the core mission program, the SSEC considered it unrealistic to anticipate a return to planetary budgets of $500 million or more a year. On the other hand, it recognized that if the launch rate of planetary missions becomes too low, then economies resulting from inheritance and common operation systems will evaporate.

The missions in the core program that follow the Venus Radar Mapper fall very roughly into two cost categories: the inner planet missions based on derivatives of Earth-orbital spacecraft, which are estimated to cost on the order of $100

million to $150 million, and the Mariner Mark II missions, which approach $250 million to $300 million in recurring costs (*33*). To sustain momentum in either program a launch about every two years is required. This is also the launch rate required to carry out most of the recommended core missions between 1988 and 2000. We therefore estimate an annual cost for flight programs, exclusive of mission operations or data analysis, of about $150 million to $200 million.

Two other essential elements of the planetary budget, in addition to flight missions, are funds for basic research (including analysis of data from past missions and planning for future flights) and for mission operations. The minimum for data analysis and research is about $100 million per year, while mission operations can, with implementation of a common operating system and use of new technology to reduce costs, be held to about half this value. Both of these items must be added to the cost of flight missions in establishing the base cost of planetary exploration.

The SSEC core program requires a sustained annual funding level of $300 million to $350 million in current (FY 1984) dollars. This level, which is about one-third of the high level of a decade ago, is sufficient to support a vigorous program of individually modest missions, and it promises to return a great deal of high-quality scientific data in a cost-effective manner.

Management Implications

The proposed core mission program represents a new approach to NASA's planetary program, and its success will depend on certain modifications of current practice. Primarily these reflect the interrelations among the proposed missions. Much of the efficiency of the approach can be realized only if the individual missions are closely spaced and planned to make maximum use of human and material resources, including the unique capabilities of the NASA centers. If treated as episodic, isolated events, these missions are unlikely to be accomplished in a cost-effective manner. Therefore, the recommended SSEC core program assumes a long-term commitment to planetary exploration with reasonably constant funding levels.

For these goals to be accomplished, the core program should be judged in terms of overall effectiveness and managed for maximum return from the entire program, not from each mission individually. The SSEC strongly urges that the inner planet missions in particular be treated as a continuing series, modeled after the highly successful Explorer program in the NASA Astrophysics Division (*34*). We endorse the concept of a similar Planetary Observer effort, funded as a level-of-effort program at about $60 million per year (in FY 1984 dollars), out of which the proposed inner planet missions would be supported. (These funds include about $10 million per year to be used for support of U.S. investigators on international planetary missions.) We urge that a similar management approach be taken for the Mariner Mark II missions, although we recognize that the magnitude of these missions makes it likely that each will require scrutiny as an individual "new start" when full-scale development begins (*35*). We recommend the rapid development of a common mission operations system in the planetary area, to be used for both Observer and Mariner Mark II missions.

Missions Beyond the Core Program

Many important scientific goals are excluded from the core program on the basis of cost and technological challenge. These include the return of samples from Mars, the exploration of the martian surface with mobile landers, the return to Earth of pristine fragments from a comet, and the operation of a buoyant station in the atmosphere of Titan. Such missions would provide scientific data fundamental for understanding the origin and evolution of the solar system, and they could generate the kind of public enthusiasm and international acclaim associated with Apollo, Viking, and Voyager. In addition, meeting such challenges would contribute to the strength of high technology in the United States. Challenging larger missions should be accepted (*36*). However, our first priority is to restore and maintain the health of planetary exploration in this nation, and we believe the core program approach advocated by the SSEC contributes to this goal.

References and Notes

1. M. M. Waldrop, *Science* **217**, 1012 (1982).
2. The NASA planetary budget reached record lows of $210.0 million in fiscal year (FY) 1982 and $186.4 million in FY 1983. For comparison, the funds appropriated in peak years FY 1973 and FY 1974 (when the Viking and Voyager missions were under full-scale development) were each over $900 million in FY 1984 dollars.
3. The last opportunity for a U.S. mission to Halley passed in FY 1982. However, fast-flyby spacecraft are being sent to the comet by the U.S.S.R. (Vega), the European Space Agency (Giotto), and Japan (Planet B).
4. The membership in the SSEC is: A. Albee, Caltech–Jet Propulsion Laboratory (JPL); K. Anderson, University of California, Berkeley; J. Arnold, University of California, San Diego; C. Barth, University of Colorado; G. Briggs, NASA headquarters; T. Donahue, University of Michigan; M. Duke, NASA/Johnson Space Flight Center; L. Fisk, University of New Hampshire; L. Haskin, Washington University; N. Hinners, NASA/Goddard Space Flight Center; D. Hunten, University of Arizona; H. Klein, NASA/Ames Research Center; E. Levy, University of Arizona; J. Martin, Martin Marietta Corp.; H. Masursky, U.S. Geological Survey; D. Morrison, University of Hawaii; J. Naugle, Fairchild Space and Electronics Corp.; J. Niehoff, Science Applications, Inc.; T. Owen, State University of New York Stony Brook; D. Rea, Caltech–JPL; L. Soderblom, U.S. Geological Survey; E. Stone, Caltech; J. Veverka, Cornell University; and L. Wilkening, University of Arizona. An additional 40 planetary scientists participated in the preparation of the SSEC report through service in five topical working groups or through supporting studies carried out at NASA centers.
5. A detailed report on the SSEC core program [*Planetary Exploration Through Year 2000: A Core Mission Program* (NASA, Washington, D.C., in press)] should be available by 1 June.
6. The number of workers in this field is estimated from such data as the 1983 membership in the Division for Planetary Science of the American Astronomical Society (450), 1981 membership in the Planetology Division of the American Geophysical Union (694), attendance at the 1982 NASA Lunar and Planetary Science Conference (557), and number of principal investigators in the NASA planetary research grants programs (422).
7. As a result of its assessment of the rationale for planetary exploration, the SSEC recommends the addition of the following fourth objective: "to provide a scientific basis for the future utilization of resources available in near-Earth space." The committee rejected recommending a narrower overall focus for the program, such as concentration on missions leading to manned exploration of Mars, since it believes the primary aim should continue to be broad scientific exploration of the planetary system.
8. For example, data on the concentrations of isotopes of the noble gases in the atmospheres of Venus, Earth, and Mars, which are critical for understanding the origin and early evolution of the terrestrial planets, were not obtained until 1976 for Mars and 1979 for Venus—11 and 17 years, respectively, after initial flybys of these planets. See, for example, T. Donahue and J. B. Pollack, in *Venus*, D. M. Hunten and L. Colin, Eds. (Univ. of Arizona Press, Tucson, 1983), pp. 1003–1031; L. M. Mukkin, in *ibid.*, pp. 1037–1045.
9. Mariner 10 photographed half the surface of Mercury during its flybys in 1973 and 1974. The surface of Venus, hidden beneath thick clouds, has been probed by ground-based and Pioneer Venus radar, but their best resolution of ~ 50 km is insufficient to reveal any but the grossest topographic features.
10. Voyager 2 is on a trajectory that will yield a flyby of Uranus in 1986 and of Neptune in 1989; the spacecraft was not designed for operation beyond the 1981 Saturn encounter, so the anticipated results from the Uranus and Neptune flybys remain uncertain.
11. H. E. Newell, "Beyond the atmosphere," *NASA Spec. Publ. SP-4211* (1980).
12. *Report on Space Science 1975*; *Strategy for Exploration of the Inner Planets: 1977–1987*; and *Strategy for Exploration of Primitive Solar System Bodies—Asteroids, Comets, and Meteorites: 1980–1990*; the three reports were published by the National Academy of Sciences, Washington, D.C.
13. In fact, costs of planetary missions in recent years have increased only modestly relative to inflation. Much of the high cost for Galileo has resulted from repeated delays and reconfigurations imposed by the Shuttle and its upper stages; in their absence, Galileo would have cost less than Voyager. However, it is clear that the absolute cost of missions is of great concern, and there has been little emphasis on applying new technology to reduce cost rather than enhance spacecraft capabilities.
14. Inevitably, this constraint eliminates from the core program a number of missions that address high-priority science goals identified by the Space Science Board. Examples are Mars sample return missions and the exploration of the martian surface by mobile laboratories.

15. Modification of the Centaur to carry out planetary missions with the Shuttle is under way, with the first launches scheduled for Galileo and the International Solar Polar Mission in 1986. Many missions in the core program could also be carried out with the solid-fuel Inertial Upper Stage, but with less margin and consequently greater risk of unanticipated costs.
16. Examples of such spacecraft with a potential planetary application are the Hughes Aircraft Co. HS-376, the TRW (Navy) Fleet Communications Satellite (FLTSATCOM), and the RCA Defense Meteorological Satellite Program (DMSP). The SSEC believes that appropriate derivatives of these spacecraft could be acquired for under $90 million (in FY 1984 dollars, and exclusive of scientific instruments and mission operations costs).
17. M. Neugebauer, *Science* **219**, 443 (1983).
18. H. Masursky *et al.*, *J. Geophys. Res.* **85**, 8232 (1980); G. E. McGill *et al.*, in *Venus*, D. Hunten and L. Colin, Eds. (Univ. of Arizona Press, Tucson, 1983), pp. 69–130.
19. Mariner 9 discovered the giant volcanoes, ancient water channels, aeolian deposits, layered polar caps, and other terrain types that reveal the varied climatic and geological history of Mars. Subsequent Viking orbiter photography increased the imaging resolution for much of the planet to ~ 100 m.
20. Development funds of $29 million are included in the Administration's FY 1984 budget request. If approved, VRM will be the first planetary new start since Galileo in FY 1978.
21. The VOIR mission was proposed as an FY 1982 new start in the Carter Administration budget but was dropped from the revised FY 1982 budget of the Reagan Administration.
22. Geochemical mapping of the moon by x-ray and gamma-ray spectrometry was carried out from lunar orbit during the Apollo program but never extended beyond the equatorial regions. Improved instruments in polar orbit would generate the global perspective needed for proper interpretation of the Apollo lunar samples and could also search for postulated reservoirs of frozen water in permanently shaded regions near the poles.
23. The Earth-approachers are small asteroids in relatively unstable orbits (lifetimes ~ 10^6 years) that approach or intersect that of Earth. They may be derived from the main asteroid belt or they may represent extinct comet nuclei, or probably both. Their small sizes, unstable orbits, and unknown provenance argue for consideration separate from the larger asteroids in stable orbits between Mars and Jupiter.
24. T. Gehrels, Ed., *Asteroids* (Univ. of Arizona Press, Tucson, 1979); L. Wilkening, Ed., *Comets* (Univ. of Arizona Press, Tucson, 1982).
25. D. L. Roberts, Ed., *Proceedings of the Cometary Science Working Group—Yerkes Observatory (June 1971)* (ITT Research Institute, Chicago, 1971); M. Neugebauer *et al.*, Eds., "Space missions to comets," *NASA CP-2089* (1977); M. Belton, Ed., "A first comet mission," *NASA Tech. Memo. TM-78420* (1977).
26. Encke is the most difficult of the three comets from an engineering point of view because its orbit takes it closer to the sun than Mercury. Tempel 2 has suitable apparitions in 1993 and 1999, and HMP in 1995. Other possible targets include Kopff (1996) and Wild 2 (1997).
27. Atomized (or plasmatized) sample return was first proposed for Comet Halley in 1981. Laboratory simulations suggest that major elemental and isotopic abundances can be measured with sufficient precision to distinguish among major meteorite types and even to yield an Rb-Sr model age.
28. A number of attractive missions would use a Mars-powered flyby for extra propulsive capability [C.-W. Yen, *AIAA Paper 82-1463* (1982)]. These are primarily combinations of a single orbit target with multiple flybys, but in a few cases the spacecraft could orbit two different main-belt asteroids. If a low-thurst ion propulsion system were available, many more such multiorbiter missions would be possible.
29. Vesta, with a diameter of 550 km, has a unique basaltic surface indicative of a complex and dynamic thermal history. Many meteoriticists consider it the parent body of the eucrite group of meteorites [see M. J. Drake, in *Asteroids*, T. Gehrels, Ed. (Univ. of Arizona Press, Tucson, 1979), pp. 765–782].
30. To reach Saturn, a Shuttle/Centaur-launched orbiter spacecraft requires a so-called delta-Vega trajectory with gravity assist from an Earth flyby about a year after launch. In contrast, with a direct flyby trajectory it would take only 3.5 years to reach Saturn.
31. Ideal times to launch spacecraft recur at roughly 13-year intervals, when Jupiter is in position to provide a gravity assist. Voyager took advantage of this planetary alignment in 1977. The next opportunity will be in 1992—unfortunately, too early in the sequence of core missions to be utilized. Uranus can still be reached during the 1990's without a Jupiter boost, but we have had to drop Neptune from the targets in the core program.
32. We anticipate that some of the missions in the core program will be carried out by other nations, perhaps jointly with NASA. For example, of the missions under consideration by the ESA, Kepler is similar to our Mars Aeronomy Orbiter and Aqora to our Main Belt Asteroid Multiple Orbiter/Flyby, while the U.S.S.R. Venera program could accomplish the objectives of the Venus Atmospheric Probe.
33. Following usual NASA practice, estimated costs, in FY 1984 dollars, exclude the cost of launch vehicles and of the Deep Space Tracking Network. Mission operations and data analysis are also budgeted separately.
34. NASA's Explorers have recently been supported at a level of about $35 million per year, and it is proposed that this be increased to $50 million beginning in FY 1984. Recent examples of Explorers are the UHURU X-ray Observatory, the International Ultraviolet Observatory (IUE), the Dynamic Explorers (DE's), the Solar Mesosphere Explorer (SME), and the Infrared Astronomy Satellite (IRAS).
35. A similar argument for continuity of funding throughout the space science program has recently been made by the Congressional Office of Technology Assessment ("Space science research in the United States," OTA Technical Memorandum, September 1982).
36. During 1983, the SSEC is undertaking a study of larger missions that might be included in an augmented planetary program.
37. The activities of the SSEC are supported by the NASA Advisory Council and the Earth and Planetary Exploration Division of NASA headquarters. We thank the members of the SSEC and its working groups, the supporting staffs at Jet Propulsion Laboratory and Ames Research Center, and especially G. Briggs, executive director of the SSEC, for their invaluable contributions to this effort.

G. FOREIGN PROGRAMS

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military affairs abroad

MILITARY IMPLICATIONS OF INDIA'S SPACE PROGRAM

FIRST LIEUTENANT JERROLD F. ELKIN
CAPTAIN BRIAN FREDERICKS, USA

IN A COUNTRY where the bullock cart still constitutes a principal mode of transportation, India's space program stands out as a dramatic achievement. Although New Delhi has consistently maintained that the space program bears no relation to defense requirements, India could produce an intermediate-range ballistic missile (IRBM) by the end of the decade assuming requisite political determinations are made. This article identifies the present accomplishments of India's space effort and discusses near- and mid-term program objectives. Further, it

examines potential military application of Indian space technology and analyzes those factors most likely to enter New Delhi's decision calculus respecting development of a nuclear weapon carrier missile system.

India's Space Achievements

On 18 July 1980, India successfully launched the Rohini I satellite and thereby became the sixth nation—after the Soviet Union, the United States, France, Japan, and China—to orbit a satellite with an indigenously produced launch vehicle. This event demonstrated that, in the eighteenth year of its existence, India's space program had become a truly sophisticated enterprise. In an organizational sense, the program began in 1962 with the creation of the Indian National Committee for Space Research under the Department of Atomic Energy. The formation of the Indian Space Research Organization (ISRO) in 1969 highlighted the transition of the space effort from a scientific undertaking of limited magnitude to a coordinated program with specific goals and time-bound projects in space applications and technology. The program's organizational structure was further augmented in 1972 with the establishment of a Space Commission and a Department of Space. The Space Commission is responsible for general policy formulation and approval of the budget of the Department of Space. The Department of Space is tasked with planning, programming, and resource allocation. The ISRO is a constituent element of the Department of Space.[1]

Professor Satish Dhawan, Chairman of the Space Commission and ISRO and Secretary to the Government in the Department of Space, has been the driving force behind India's space undertakings. Under Dhawan, India has made material progress in the areas of satellite and launcher development and ground support infrastructure expansion. While Dhawan has emphasized the need to enhance indigenous capability in all aspects of space technology, he has recognized that, as an interim step, acceptance of foreign assistance is imperative. Such assistance, in the form of satellite design support and actual launching of Indian satellites, has come from the United States, the U.S.S.R., and France.

On 19 April 1975, India's first satellite, the 35 kg Aryabhata, was placed in a 600 km circular orbit by a Soviet rocket. The launching of Aryabhata demonstrated the ability of Indian scientists to design and fabricate orbital satellites. With the exception of the solar panels and batteries, all of Aryabhata's systems were manufactured in India. Beyond this, the Indians evidenced an ability to employ receiving, transmitting, and tracking facilities for the purpose of satellite monitoring.

India's second experimental satellite, the 444 kg Bhaskara, was launched in June 1979 from the U.S.S.R. on a Soviet rocket. The Bhaskara carried two remote-sensing payloads: a television camera and microwave imaging system. However, the TV camera failed to operate for nearly a year. After an extensive simulation exercise, Indian scientists were able to remedy the problem, and in May 1980 the satellite began transmitting as many as ten pictures a day. The quality of the nearly 1000 pictures sent back by Bhaskara's TV camera compared favorably with similar pictures taken by other meteorological satellites.[2]

While the Aryabhata and Bhaskara were placed in orbit by Soviet boosters, Indian efforts to design and fabricate a satellite launch vehicle continued apace. An indigenously produced four-stage, solid fuel rocket, designated the SLV-3, made its maiden flight on 10 August 1979. A malfunction in the second stage caused a flight termination after only 317 seconds. However, in July 1980, the SLV-3 successfully injected the 35 kg Rohini I satellite into near-earth orbit. The primary objectives of the Rohini I were performance evaluation of the SLV-3 and determination of the satellite's orbital characteristics.[3] The magnitude of this achievement becomes apparent when one considers that Japan, a technologically advanced nation, was

unable to put a satellite into space until its fifth attempt.

The year 1981 witnessed an acceleration of India's space activity. In May, the second Rohini satellite, with an expected mission duration of 300 days, was placed into an elliptical orbit. The Rohini carried a landmark sensor of Indian manufacture capable of photographing areas 250 by 80 km with a resolution of 1 km. However, a problem in the fourth stage resulted in a failure to achieve required orbital altitude; in consequence, Rohini II reentered the earth's atmosphere after only nine days in space. In June, India's first geostationary satellite was launched by the European Space Agency from French Guiana. This satellite, known as APPLE (Ariane Passenger Payload Experiment), was meant to serve as a test bed for India's communication satellite program. The most critical phase of the APPLE mission profile involved employment of an apogee boost motor to shift the spacecraft from a transfer to a drift orbit, from which the satellite was maneuvered to its permanent station.[4] The success of Indian scientists in correctly positioning APPLE was trumpeted by the Indian press, which emphasized that this capability had been previously demonstrated only by the United States, the U.S.S.R., France, and Canada. In November 1981, Bhaskara II, India's second earth observation satellite, was launched from a Soviet cosmodrome. Unlike its predecessor, the Bhaskara II experienced no problems with its cameras. This satellite provided information, inter alia, on cloud formation and atmospheric moisture content.

India's communication capability will be further enhanced with the initiation of Indian National Satellite (INSAT) operations. In addition to telecommunications and direct TV broadcasting, the INSAT system will have a meteorological earth observation and data relay mission. Two INSAT spacecraft have been fabricated by a U.S. firm according to Indian specifications. INSAT's ground support equipment will include thirty-five tracking stations, six of these being mobile facilities.

INSAT-1A was launched from the Kennedy Space Center on 10 April 1982 and inserted into a geosynchronous orbit on the thirteenth. However, a premature exhaustion of thruster propellant resulted in a cessation of operations only 150 days after launch. Nevertheless, New Delhi remains satisfied with the basic design, and a 1983 launching of INSAT-1B is anticipated.

Projected Space Development Programs

The Indians have embarked on a number ot satellite development projects to be completed by the end of the decade. Among these is proto-INSAT, which will be used in establishing design parameters for indigenously built INSAT replacement satellites. However, it is in the area of booster technology that impressive advances can be anticipated in the near term. During the 1980s, India intends to produce an augmented satellite launch vehicle (ASLV) and a polar satellite launch vehicle (PSLV). The ASLV will consist of an SLV-3 with two first-stage SLV-3 rockets as strap-on boosters. The ASLV will be able to inject a 150 kg payload into low-earth orbit, as compared with the 35-50 kg lift capacity of the SLV-3. As presently configured, the PSLV will consist of a solid fuel booster with six strap-on motors derived from the SLV-3 first stage, a liquid fuel second stage, and two solid fuel upper stages. This launch vehicle, designed to place a 1000 kg payload into a 900 km polar sunsynchronous orbit, is expected to be operational by 1987.

Dr. Abdul Kalam, head of launch vehicle development in the ISRO, has declared that by 1990 India will be able to position a 2500 kg communication satellite into geosynchronous orbit at 36,000 km. He has further asserted that the ISRO can produce a cryogenic rocket engine (using liquid oxygen and liquid hydrogen) during the 1980s. The Indians consider cryogenic engines more cost effective than rockets employing solid or storable liquid fuel because of greater thrust generation and the possibility of reduced vehicle size.[5]

Military Implications of Space Research

The Indian leadership has emphasized that advances in rocket and satellite technology will not be translated into an enhanced military capability. Thus, for example, the Minister of State in the Ministry of Defense apprised Parliament after the launching of Rohini I that no plans existed for the manufacture of IRBMs.[6] Despite such pronouncements, potential military applications of Indian space technology are manifold, to include development of reconnaissance satellites, improvements in command and control, greater precision in operational planning based on satellite-derived meteorological data, and IRBM production.

reconnaissance satellites

India has already designed a satellite camera system and placed it into orbit. While the resolution of the Rohini II landmark sensor was inadequate for detailed surveillance activity, it would have allowed New Delhi to locate road and rail nets in neighboring countries. The 1981 acquisition of advanced MiG-25 Foxbat reconnaissance aircraft from the Soviet Union evidences India's interest in improving its ability to monitor military installations and troop movements in Pakistan and China. The production of satellites (employing sophisticated optics either indigenously fabricated or acquired from third countries) would appreciably augment India's existing photographic intelligence resources.

command and control

A substantial upgrading of India's domestic communication infrastructure constitutes a fundamental objective of the INSAT program. The INSAT-1B platform will have twelve communication channels, each able to handle 2000 telephone conversations, plus two direct broadcast television channels. The applicability of such an information transmission system to defense requirements is patent. Thus, for example, the six mobile down links associated with INSAT may well prove forerunners of systems integrated into army units that will enable these units to deploy from peacetime cantonments with little or no communication disruption. Similarly, satellites could increase the effectiveness of the Indian Navy both by ensuring continuous communication with all naval vessels and improving the accuracy of maritime navigation. In this context, it must be appreciated that India's armed forces comprise the world's fourth largest army, the fifth largest air force, and a navy transitioning from a coastal defense force to a blue-water fleet. A military organization of this magnitude, with installations distributed throughout India and numerous warships at sea, would derive particular benefit from a satellite-enhanced C^3 network.

weather forecasting

Weather conditions form a critical variable in military planning. The greater precision in weather forecasting afforded by Indian meteorological satellites will, in consequence, materially assist planners in structuring military exercises or actual combat operations.

intermediate-range ballistic missiles

The Indian political leadership has consistently asserted that the activities of the Department of Space are nonmilitary in nature. However, Satish Dhawan declared in 1979 that the SLV-3 could be converted into an IRBM with a range of approximately 1500 km.[7] Adoption of such a course of action would appear to have the support of India's armed forces. An editorial in the November 1981 edition of *Vikrant*, a semiofficial Indian military publication, states that India ". . . must possess adequate capability for strategic long-range strike in the form of MRBM/IRBMs equipped with nuclear warheads, a strategic air strike and interdictor force and adequate air defence, all equally complementary and coordinated."[8]

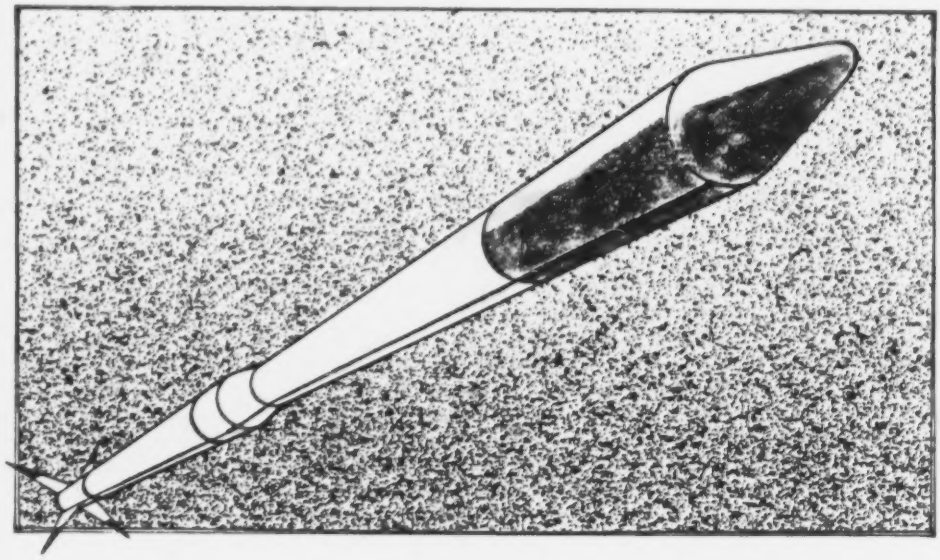
Modification of the SLV-3 into a nuclear-

weapon-carrier missile involves more than mere payload substitution; rather, a number of significant technological difficulties must be surmounted. First, a reentry heat shield capable of withstanding temperatures of several thousand degrees centrigrade must be developed. It has been reported that Indian scientists are presently endeavoring to perfect an ablative heat shield system that would satisfy this requirement.[9] Second, sophisticated guidance systems are needed to ensure that warheads arrive at their targets. India's demonstrated capability to maneuver a satellite into geosynchronous orbit evidences possession of sensitive position-correcting instruments. A senior Indian scientist has asserted that such guidance systems could be applied to defense purposes after modest refinement.[10]

Indian military affairs analyst R. R. Subramanian notes that the SLV-3, a four-stage launcher using solid propellant motors, is far from an ideal weapon delivery vehicle. The disadvantages of a four-stage rocket are said to include the need to integrate control and guidance equipment with each of the stages and the increased likelihood of engine malfunction. Further, the solid propellant rockets of the SLV-3 cannot generate as much thrust as liquid-fuel engines (and thus have a lesser payload- lift capability[11] In this regard, it should be appreciated that India is currently designing a liquid-fuel rocket which, in combination with solid fuel rockets, will form the PSLV power plant.

In sum, it is probable that, given a political decision to manufacture nuclear bombs and a missile delivery system for such weaponry, India could have an operational IRBM force by the end of the decade. Indeed, a senior ISRO official has observed that India could develop an IRBM prototype within two years.[12]

The SLV-3 was designed and developed to put the 88-pound Rohini satellite into near-earth orbit. Its second flight on 18 July 1980 was successful, making India the sixth nation to orbit a satellite of its own creation.



Factors Influencing India's Decision to Develop IRBMs

Prime Minister Indira Gandhi has repeatedly maintained that India's nuclear program is dedicated to peaceful and constructive purposes. However, many influential figures have articulated the view that development of nuclear weaponry is imperative. The late Air Chief Marshal P. C. Lal, former head of the Indian Air Force, asserted that "India has the capability to make the atom bomb at short notice and should integrate it in its military arsenal and build up its defence strategy and tactics around it." He further advocated the establishment of training programs to familiarize Indian armed forces with nuclear warfare.[13] K. Subrahmanyam, director of the Institute for Defence Studies and Analysis (an autonomous but government-funded body that serves as a principal actor in the formulation of defense policy), observed that "India has to keep a few steps ahead of Pakistan in nuclear weapon technology and develop the infrastructure to be in a position to deter Pakistan when it reaches nuclear capability."[14] If Pakistan does in fact explode a nuclear device, pressure applied by India's "nuclear bomb lobby" may prove irresistible. If the decision to develop nuclear weaponry is made, the question of an appropriate delivery vehicle must be addressed.

Pakistan

There is no need to employ ballistic missile assets against Pakistan. Strike aircraft presently maintained by India (namely, the Canberra medium bomber, the Anglo-French Jaguar, and the Soviet MiG-23 Flogger, along with the French Mirage 2000 to be acquired during 1984-85) can hit targets throughout Pakistan with nuclear bombs.

It should be noted parenthetically that there is no uniformity of opinion within India regarding the indispensability of countering Pakistani nuclear weaponry with equivalent Indian weaponry. Rather, some analysts believe that a Pakistan armed with several crude nuclear bombs could be readily defeated by India's overwhelming conventional strength.[15]

China

India considers China to be its chief strategic threat. This perception results in part from the severe defeat suffered by New Delhi in the 1962 Sino-Indian War. India reacted to this defeat by substantially augmenting military force levels along its northern and northeastern borders. Today, an appreciable percentage of India's ground and air strength is oriented toward China. However, India's conventional arms cannot offset the threat presented by China's medium- and long-range ballistic missile inventory.

India is endeavoring to meet the Chinese threat by diplomatic as well as military means. In December 1981, efforts to resolve Sino-Indian differences regarding demarcation of their common border were reinstituted after twenty-one years; subsequent rounds of talks occurred in May 1982 and January 1983. It is far from certain, however, that these border negotiations will be satisfactorily concluded. Thus, for example, an exacerbation of tensions between India and Pakistan, a principal Chinese ally, could lead to a termination of discussions. The talks could also collapse if India and China are unable to overcome decades of ill-feeling and mutual suspicion. In such circumstances, India's possession of an IRBM force would prove of marked utility, serving to inhibit active Chinese intervention in any future Indo-Pakistani conflict and deter a Chinese attack against India.

Indian Ocean

India appreciates that its regional maritime interests can be secured only through an increased power presence. This in large measure accounts for the emphasis being given to the development of a blue-water navy. The addition

of ballistic missiles to New Delhi's weapon inventory would materially enhance its ability to project military force throughout the Indian Ocean. Increased attention paid to Indian security concerns by outside powers operating in the region (for example, the United States, with its Diego Garcia base) would prove an attendant benefit.

psychological and prestige factors

India wishes to be recognized as a technologically advanced state. The desire to instill this perception was, in addition to military and scientific considerations, a driving force behind the 1974 explosion of a nuclear device. Similar motivations have impelled the establishment of the space program and, to a great degree, stimulate interest in the development of IRBMs.

The political significance of an IRBM force is also not lost on the Indian leadership. Only a few major powers have a ballistic missile production capability. Should India join this group, it would doubtless facilitate efforts at realizing an international security role commensurate with its size and potential. Furthermore, New Delhi would be able to resist the strategic demands of great powers that might otherwise have to be accommodated.[16]

nonaligned movement

Maintenance of India's status as a leader of the nonaligned movement is one of Mrs. Gandhi's central concerns. The manner in which procurement of nuclear weapons and carrier missiles would impact on this policy objective is therefore an issue of considerable moment. In consequence, the Indian government must weigh the likelihood of ballistic missile production raising India's stature in the Third World or, in the alternative, isolating New Delhi within the nonaligned movement by generating apprehension regarding Indian intentions.

economic factors

India's space program expenditures totaled $330 million during the period 1962-80. The relative frugality of this enterprise resulted in part from the willingness of the Soviet Union and the European Space Agency to launch Indian satellites at little or no cost. The dramatic growth of space activity in the 1980s will necessitate a financial outlay of approximately $1.1 billion, a figure that will increase appreciably if space technology is applied to defense requirements. However, such amounts are far less than the costs associated with India's present force modernization effort. In 1979, India signed a $1.7 billion contract with the United Kingdom for Jaguar strike aircraft; in 1980, weapon procurement agreements totaling more than $2 billion were concluded with the Soviet Union and West Germany; and in 1982, India purchased Mirage 2000 multimission aircraft from France at a cost of nearly $1 billion. Therefore, it would appear that, if deemed militarily imperative, economic factors will not dissuade the Indian government from developing a ballistic missile force.

THERE IS NO EVIDENCE to suggest that New Delhi is currently employing space program assets to satisfy defense requirements. It must be recognized, however, that many of the accomplishments of India's space scientists have direct military applicability. Further, the lead time needed to convert satellites and launchers from civilian/scientific to military end use will diminish as India's space effort becomes more sophisticated. Undoubtedly, India's leadership would authorize such a program reorientation should this course of action be deemed advantageous.

Defense Intelligence Agency
and
George Washington University

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Soviets Developing 12-Man Space Station

Work includes new launcher; military objectives dominate effort, but scientific, lunar, planetary goals involved

By Craig Covault

Washington—Soviet Union is developing a 220,000-lb. military/scientific space station to be manned permanently in earth orbit by about 12 cosmonauts following launch in the mid-1980s on board a 10-14-million-lb. thrust booster more powerful than the U. S. Saturn 5.

Establishment of the station will raise concern over increased Soviet strategic capability. Military objectives are expected to dominate the multidisciplinary station and could include photo and electronic intelligence and the first large-scale development of space-based, directed-energy weapons.

The massive new booster and space station will provide the USSR with a solid base on which to mount the first manned missions to Mars in addition to initial Soviet manned lunar flights. The station will, for the first time, involve large numbers of persons permanently working in orbit; a fundamental step toward establishment of colonies in space.

In addition to resumption of substantial work on a Saturn 5 class vehicle, Russian emphasis is expected soon on other Soviet heavy boosters. This indicates the U. S. may be entering an era in which extensive Soviet launch vehicle capabilities alone could be a dominant factor in the strategic use of space compared with even the substantial benefits expected from the U. S. space shuttle.

The 220,000-lb.-class station will be about 10 tons larger than the U. S. Skylab space station and dwarf the 42,000-lb. Russian Salyut station currently in operation. Analysis indicates the booster will be about 300 ft. long with a 50-ft. base diameter, housing 24-36 first-stage engines generating 10-14 million lb. of liftoff thrust. The U. S. Saturn 5 was 363 ft. tall and had a 33-ft.-dia. base with five Rocketdyne F-1 first-stage engines generating a total of 7.5 million lb. of thrust.

The Soviets earlier attempted development of their Saturn 5 class booster in the late 1960s but then mothballed the development after three flight failures (AWAST Apr. 9, 1973, p. 21) and the achievement of the first lunar landing by the U. S.

In addition to renewed development of their Saturn 5 class booster, the Soviets are expected to make increased use of their largest operational booster, the Proton, which has a maximum payload-to-orbit capability of about 45,000 lb., compared to the U. S. Saturn 1B, which had about a 36,600-lb. capability to low earth orbit and the operational Titan 3D with a 30,000-lb. capability.

The Soviets have stated consistently that their ultimate goals in space are per-

Reproduced with permission of the copyright holder from Covault, Craig. Soviets developing a 12-man space station. Aviation week & Space Technology, v. 112, June 16, 1980: 26-29. (c) Aviation week & space technology, McCraw-Hill, Inc.

manently manned space stations and manned flights to the planets, primarily Mars. The two new developments are in direct line with those goals. The Soviets have consistently played down the significance of the Apollo lunar landing program, but U.S. analysts believe this equates to "political sour grapes." With an operational booster capable of placing at least 220,000 lb. in low earth orbit, a lunar landing would be well within reach of the USSR as a stepping stone to Mars. Pursuit of in-orbit vehicle assembly facilitated by the large crew of cosmonauts planned for the space station could assist both manned lunar and manned Mars mission activities.

Current work on the giant new booster could result in a launch attempt as early as 1983, U.S. analysts believe. Launch of the space station will be dependent on booster performance and could occur as early as 1985, U.S. analysts said.

In-orbit resupply and crew change to keep the large new Soviet station permanently manned is expected to involve another major Soviet development also under way. U.S. analysts have reaffirmed that development of a Soviet winged, manned reusable spacecraft is continuing with first launch on an expendable vehicle expected by about 1985 (AWAST Nov. 6, 1978, p. 19; Mar. 20, 1978, p. 14). This winged reusable vehicle will have nowhere near the payload capacity of the U.S. space shuttle but would be a cost-effective space station resupply vehicle. It is comparable to the USAF/Boeing X-20 Dyna Soar program, which was envisioned for space station resupply prior to its cancellation in the 1960s.

The U.S. plans nothing approaching the scale of space activity contemplated by the Soviets with their new developments, although the U.S. space shuttle will provide far easier and less expensive access to space through the 1980s than the Soviet capability will allow. What the current space shuttle program lacks, however, is a financial and planning commitment to expand the orbital stay time and electrical power capabilities of the vehicle and to exploit the shuttle's capability by moving toward space station type platforms that can fly manned missions between shuttle visits. The large booster and station developments should help the Russians maintain a lead in the important area of long-duration manned flight.

Impact of a large permanently manned Soviet space station has already been discussed by the Defense Dept. and the National Aeronautics and Space Administration.

The Defense Dept. and NASA last year jointly initiated examination of the implications of such a development. NASA Administrator Robert A. Frosch told Congress the impact on the U.S. of an operational permanently manned Soviet station "could be severe in the sense that suddenly there would be a change from experimentation to [an] operational status. I think people in general would consider it a serious event" (AWAST Apr. 9, 1979, p. 21).

Explosive expansion of Soviet space program activity over the past several years, especially in the manned area, has been possible because the Russians have been providing their program with real funding increases of 3-5% per year, a sharp contrast to the U.S. congressional and presidential attitude toward the U.S. program since the end of the Apollo project.

The Russians are believed to have at least 100,000 scientists and engineers largely devoted to space program goals, and they have been developing an average of three entirely new spacecraft types every year. New launch vehicles have been

developed at a rate of one every five years by the Russians.

The Soviets last year demonstrated their ability and willingness to devote, on relatively short notice, large numbers of expensive space vehicles to obtain nationally important data. During 1979 the Russians flew 10 recoverable film reconnaissance spacecraft on announced earth resources missions that U. S. analysts believe were launched specifically to assess world wheat crops. This was to provide the Soviets with market data in a year when their own wheat crop was below expectations.

Soviet spacecraft are expected to become larger and more complex requiring expanded use of the Proton booster, the largest operational launch vehicle in the world. Increased use of the Proton could result in an overall yearly reduction in Soviet launches as individual Soviet spacecraft become heavier and are given more capability. During 1979 the Soviets launched 87 missions carrying 124 satellite payloads. The U. S. launched 16 missions carrying 18 payloads. At least 59 of the Russian missions were military compared to five U. S. military missions last year.

The Proton is the same vehicle used to launch the Salyut space station, and it also is expected to be used to launch the new delta-winged manned reusable space vehicle. The Soviets will have to man-rate the Proton for this task, a factor that would probably involve some system rework on the vehicle since in its unmanned role the Proton has a somewhat higher failure rate than smaller Soviet boosters.

Expanding Booster Capability

While the U. S. begins to operate the 65,000-lb. payload space shuttle the Soviets will be expanding their already formidable booster capability by bringing on line their Saturn 5 class vehicle, increasing use of the standard Proton, and possibly adding a liquid oxygen/hydrogen upper stage to the Proton launcher.

The Soviets have never flown an oxygen/hydrogen upper stage, although U. S. researchers have been expecting to see this development relatively soon. Such a stage on the Proton could greatly increase the amount of payload the Soviets could launch into geosynchronous orbit.

The new Saturn 5 class booster is not expected to use oxygen and hydrogen stages as did the U. S. Saturn 5. Lack of high-energy second and third stages like those on the U. S. Saturn 5 is one reason the Soviet vehicle is expected to have a payload-to-orbit capability comparable to the Saturn 5 but to utilize a first stage with possibly twice the thrust of the Boeing S-1C, which was the Saturn 5's first stage.

Payload Weight

Earth escape payload for the Soviet vehicle will be comparable in weight to that of the Saturn 5. Earlier tests of the initial version of the Soviet vehicle failed in November, 1972; June, 1971, and June, 1969. As recently as two years ago, development of the vehicle was considered by U. S. analysts to be "on the back burner," but the development has now resumed at a pace keyed to launch of the large space station in the mid-1980s.

Another significant development in the heavy booster area involves the Russian SS-9 intercontinental ballistic missile. SS-9s have been used routinely as space launchers for many years, but recent data indicate a third stage is now added on some missions to increase the size of the payload that can be launched. SS-9 operational ICBMs now are being replaced by

the SS-18, and analysts believe it is possible that many more SS-9s will be used for space launch missions, further increasing the overall Soviet payload-to-orbit capability.

While booster power is increasing, so are Soviet electrical power capabilities in space. U. S. analysts foresee increased use of nuclear reactors for electrical power on Soviet spacecraft. Loss of the Cosmos 954 reactor-powered spacecraft over Canada, which caused a major international incident, has not slowed the Soviet reactor program, and U. S. analysts expect to see continued use of the reactor-powered radar ocean surveillance spacecraft to help expand Soviet naval warfighting capability far beyond previous bounds. U. S. analysts would not be surprised to see reactors placed on future Russian television broadcast and other communications spacecraft in the 1980s.

Reactor work in space could be important for development of directed-energy weapons in space. No Soviet laser or other directed-energy tests in space have occurred, but the U. S. believes it likely the Soviets now have an operational ground-based antisatellite laser and the basing of that system in space is a likely area of Soviet development over the next few years.

Activities on the Salyut 6 space station are a major stimulus to the new Russian space developments and already approach permanent station status but with only a two-man crew. Some U. S. analysts believe that Soviet unmanned planetary missions are receiving fewer resources now in order to pour more funds into the manned program.

Increase in size of the existing Salyut space station design is a priority in the Soviet program. One way this can be done is to leave a Soyuz orbital module docked with the vehicle as the standard crew-carrying Soyuz descent module and service module separate for a return to earth.

Salyut 6 has only two docking ports, a limiting factor in this type activity. U. S. analysts believe that as early as the next Salyut, Salyut 7, the Soviets can be expected to utilize more than two docking ports on their Salyuts in order to bring modules to the station that can be left, thus increasing the habitable space while also allowing docking ports for Soyuz return vehicles and Progress tanker resupply missions.

Soyuz T-2 spacecraft that returned Cosmonauts Lt. Col. Yuri V. Malyshev and Vladimir V. Aksenov to earth June 9 after a four-day mission, three of those days on Salyut 6, is an uprated Soyuz that is expected to be used until the Russians bring their reusable winged vehicle on line in connection with the massive space station in the mid-1980s.

The Soyuz T design includes solar arrays and an improved main propulsion and attitude control system assisted by a digital computer.

These changes should enable much more mission flexibility than the older Soyuz design, so limited on stored battery power and maneuvering propellant that it has been forced to abort space station linkups at high Salyut altitudes whenever problems occurred in the final rendezvous and docking sequence.

These new Russian developments of expanding booster power with a Saturn 5 class vehicle, development of a permanent space station larger than Skylab and planned use of winged, reusable space transports indicate that the decades the 1980s and 1990s will be full of intense Russian manned space activity. Many managers in the U. S. space program hope the military strategic and scientific significance of this major Russian development push will not be lost in planning for the space shuttle and will stimulate full use of its capabilities.

The National Security Council has recognized this Soviet advancement and during White House discussions late last year on increased space shuttle development funding that threatened the operational use of the shuttle, called President Carter's attention to the Soviet development push.

"The currently operational military and civil Soviet manned program could provide them with significant scientific, technical, political and strategic advances that cannot be overcome with a U. S. space program operating solely on expendable launch vehicles," a briefing to the President stated. "If we do not expend the thought, the effort and the money required, then another more progressive nation will."

1017

SALYUT

SOVIET STEPS TOWARD PERMANENT HUMAN PRESENCE IN SPACE

A TECHNICAL MEMORANDUM

DECEMBER 1983

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Foreword

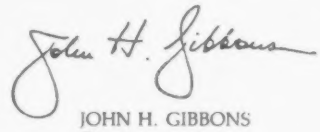
As the other major spacefaring nation, the Soviet Union is a subject of interest to the American people and Congress in their deliberations concerning the future of U.S. space activities. In the course of an assessment of Civilian Space Stations, the Office of Technology Assessment (OTA) has undertaken a study of the presence of Soviets in space and their Salyut space stations, in order to provide Congress with an informed view of Soviet capabilities and intentions.

The major element in this technical memorandum was a workshop held at OTA in December 1982: it was the first occasion when a significant number of experts in this area of Soviet space activities had met for extended unclassified discussion. As a result of the workshop, OTA prepared this technical memorandum, "Salyut: Soviet Steps Toward Permanent Human Presence in Space." It has been reviewed extensively by workshop participants and others familiar with Soviet space activities.

Also in December 1982, OTA wrote to the U.S.S.R.'s Ambassador to the United States Anatoliy Dobrynin, requesting any information concerning present and future Soviet space activities that the Soviet Union judged could be of value to the OTA assessment of civilian space stations. The result of this request is appendix A of this technical memorandum: "The Soviet Salyut Space Program: Space Station, Spacecraft, Support, and Training Facilities" is an official summary of Salyut space station activities, provided to OTA by Dr. Balayan, Vice-Chairman of the Intercosmos Council of the U.S.S.R.'s Academy of Sciences. OTA appreciates the cooperation of Ambassador Dobrynin and the Soviet Academy in providing this information. This appendix is of particular interest in that such information is seldom provided to American agencies through official Soviet channels.

Appendix B is a paper prepared for OTA by Geoffrey E. Perry, head of the Kettering Group in England. This paper, "Soviet Space Stations: Achievements, Trends, and Outlook," provides an independent view of Soviet accomplishments in this area; it is based, in part, on the Kettering Group's long-term monitoring of audio communications between the Salyuts and Soviet ground stations.

Those individuals acknowledged in appendix C provided information during the course of the study and/or reviewed the draft report.



JOHN H. GIBBONS
Director

OTA Staff for Salyut: Soviet Steps Toward Permanent Human Presence in Space

John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

Nancy Naismith, *Science, Transportation, and Innovation Program Manager*

William Mills, *Science, Transportation, and Innovation Program Manager* (until Oct. 1, 1983)

Thomas F. Rogers, *Project Director, Civilian Space Stations Assessment*

Philip P. Chandler, II, *Deputy Project Director, Civilian Space Stations Assessment*

Contractors

Leonard David Courtland S. Lewis
Al Peabody Peter Ognibene

Administrative Staff

Marsha Fenn R. Bryan Harrison

OTA Publishing Staff

John C. Holmes, *Publishing Officer*

John Bergling Kathie S. Boss Debra M. Datcher Joe Henson
Glenda Lawing Linda A. Leahy Cheryl J. Manning

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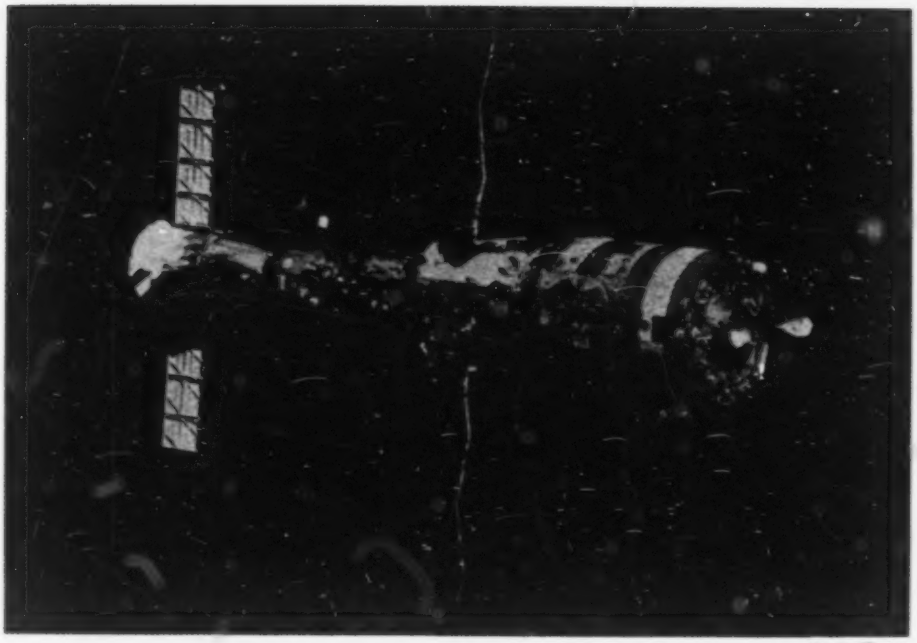


Photo credit: Tass

Orbiting complex Salyut 7—Soyuz T-5 (photo taken from Soyuz T-6 on July 2, 1982, from a distance of about 120 m)

Introduction

A number of citizens of the Soviet Union, and their guests from other countries, have visited the Earth's lower space regime; the Soviet in-orbit space infrastructure, primarily the Salyut space stations (or, as the Soviets say, "orbital stations"), has housed and supplied them there, more or less continuously, for over a dozen years. During this period the total number of hours that Soviet cosmonauts have spent in space has overtaken and is now much greater than the corresponding total for U.S. astronauts. By all accounts, the Soviets are more knowledgeable than the United States in space biology and medicine; in a number of technical areas, notably in the use of automated docking systems, they routinely use techniques that the United States has never demonstrated. It is true, on the other hand, that the Space Shuttle now gives the United States significant capabilities that the Soviets do not have, but it is widely believed on the basis of photographic evidence available from unclassified sources that the Soviet Union is developing both a small space plane and a heavy-lift shuttle expected to be capable of propelling more massive payloads into low-Earth orbit than can its U.S. counterpart.

The Soviet space station program is the cornerstone of an official policy which looks not only toward a permanent Soviet human presence in low-Earth orbit but also toward permanent Soviet settlement of their people on the Moon and Mars. The Soviets take quite seriously the possibility that large numbers of their citizens will one day live in space. Although the Soviets do not often directly communicate detailed results of what has been learned by and from the cosmonauts aboard Salyuts, enough information is available to conclude that they are accomplishing much more than rudimentary scientific investigations: they are providing the data, information, and experience required to design habitats and equipment which will allow individuals to reside for the long-term in space.

The Soviet approach to the development of space capabilities differs significantly from the American. Whereas the United States tends to advance from one space capability to the next by quantum leaps, the Soviet Union tends to modify and adapt technology that is already in hand, thereby increasing its capability in a seemingly more evolutionary or progressive fashion. By thus relying on systems flight-proved in earlier space programs, the Soviets may have been able to restrain costs and minimize the time spent in development and construction. The Soviet space program and the U.S. satellite communications industry are similar in that both allow for the establishment of gradually evolving spacecraft design, and it may be advisable for the United States, in other selected areas of space applications, for example, to adopt some form of the Soviet strategy. Already, NASA's Solar System Exploration Committee (SSEC), emphasizing the importance of system heritability, has advocated a similar approach for planetary science.

The relative merits of automated and human capabilities for performing work in space or, more precisely, the criteria for establishing the optimal mix of the automation and the human presence for particular tasks, are the subjects of considerable debate in the United States. Although the amount of time in space that American astronauts have amassed is nontrivial, there is a certain degree of unreality about this debate because it cannot yet be grounded in extensive experience. The Soviet Union, on the other hand, can draw on a much greater fund of experience as they implement plans for integrating human and machine capabilities for work on future space stations.

Perhaps the most important point to be made here is that the United States and the Soviet Union have cast the issue of humans versus machines in different terms. U.S. space policy is to explore and study space and to use it for general human benefit—and, where appropriate, to involve human beings in actual spaceflight. In addition, both the United States and the Soviet Union use their spaceflight programs involving people to enhance their national images. Soviet space policy, however, goes further; it includes the goal of learning how human beings may reside permanently in space, both as an end in itself and as a means of serving their national purposes. To date, the United States has not committed itself to permanent human occupancy of space as a national goal.

Executive Summary

The launching of Sputnik 1 initiated a space race that led to the landing of astronauts on the Moon; today the United States and the Soviet Union are well aware of their relative strengths and weaknesses in space activity. In most areas of space science and space applications—best exemplified, respectively, by the Voyager missions to Jupiter and Saturn, and the burgeoning satellite communications industry—the United States, through steady, long-term effort, seems to have gained a substantial lead over the Soviet Union.

In human spaceflight, the picture is less clear because the countries have taken quite different approaches. In some respects, the activities of the two countries in this arena have resembled the race between the tortoise and the hare: while the Soviet effort has featured apparently steady, incremental progression along well-defined lines of development, the United States has typically played catchup, using its strong technological capacity to produce space achievements of startling virtuosity. Continuing development on both sides has been fueled by a combination of political, economic, and military motives, in different order of importance at different times.

The divergent approaches of the two countries have led to two very different types of current human spaceflight capability. The Soviet Union has, since 1971, pursued a more-or-less continuous program of development of space stations in low-Earth orbit (LEO). With the sixth operational model of the Salyut series now flying, Soviet cosmonauts have logged over three times the U.S. total of crew-hours in space, and accumulated extensive experience in the conduct of flight operations, experimentation, and Earth observation in trips that last for months. However, they are currently restricted to the use of relatively small, expendable launch vehicles for crew transportation and resupply. The United States, on the other hand, has an operational space Shuttle which permits the routine ferrying of crews and large payloads into orbit for over a week, currently at the rate of some 5-6 flights per year. The Shuttle is reusable, its staytime in orbit could be increased, and the planned fleet of four Orbiters could provide staytime on the order of months per year. But an individual unmodified Orbiter does not provide a habitation combining large volume, high power, and long duration needed for many of the in-orbit research and development activities of interest, particularly to the life sciences and some in the private sector.

The National Aeronautics and Space Administration is now considering "the next logical step" for its space program: the establishment of a potentially permanent human presence as part of an actually permanent LEO infrastructure, i.e., what NASA describes as a civilian space station. If the administration formally proposes to begin work on such infrastructure, then Congress may find that a detailed examination of the Soviet human presence in space, the Salyut space stations, and their associated space vehicles, can provide a useful frame of reference.

Early in this century, Konstantin Tsiolkovsky, a Russian scientist and engineer, provided the theoretical underpinnings for the Soviet space program with his visionary writings about the use of orbiting stations as a springboard for exploring the cosmos. One can still find the influence of his theories in the statements of modern-day Soviet leaders.

But Soviet scientists and technicians have found that the road to realizing their dream is a long and difficult one. After initial successes with Sputnik and the early orbital flights of cosmonauts in the one-seat Vostok capsule, the Soviet space program began to feel the limitations of its technology. The 6-metric-ton (tonne; one tonne = 2205 lbs) Voskhod flew only twice, Voskhod 1 with three crewmembers, Vockhod 2 with two. Two years later, in 1967, a new space vehicle debuted with Soyuz 1. Despite the death of the first Soyuz pilot in a crash landing, the Soyuz-class ship eventually became the principal means of putting cosmonauts into space. After 12 years of Soyuz operations, a new design, Soyuz T, made its inaugural flight in 1979.

In the late 1960's, the Soviets appeared to be intent on sending cosmonauts to the Moon, but, in view of the success of the U.S. effort to do so, they eventually settled for landing automated

probes on the lunar surface. Subsequently, the focus of the Soviet manned space program shifted exclusively to the establishment of a strong capability for near-Earth orbital operations, i.e., the development of space stations and associated space vehicles. When Soyuz 4 docked with its sister ship Soyuz 5 in January 1969, the Soviets called the resulting complex "the world's first space station," although the two craft had no connecting passageway between them. Salyut 1, which provided one continuous volume capable of supporting human habitation for time-periods of the order of months, went into orbit in 1971; the most recent of the series, Salyut 7, was launched in 1982 and remains operational today.

Some of the Salyut stations were apparently military in function; others seem to have been primarily civil. With Salyut 6 and 7, the distinction became blurred; it may be that the military no longer has a separate Salyut program. The Soviets have maintained total secrecy in military operations, but they have gradually become more open with their civilian programs, broadening the makeup of their crews to include members from Eastern Europe and other Soviet-bloc countries, France, and, soon, India. Although any joint U.S.-Soviet effort (e.g., the symbolic joining of the Apollo and Soyuz in orbit in 1975) currently seems unlikely, future Soviet missions will probably continue to be international to some degree.

The fact that the Soviet technological base remains relatively narrow seems to be closely coupled with the infrequency with which rapid innovation is achieved, both in Soviet industry generally and in the Soviet space program in particular. Although Soviet spacecraft designers rely heavily on automated control with cosmonauts as backups, crewmembers have, in many instances, assumed broader duties to make up for failures in automation. In any case, Salyut has afforded its crews of engineers and cosmonauts extensive experience in conducting operations in space. Precisely how this experience will be put to use in future operations is unclear.

Salyut may be the penultimate step leading to a permanent, large-scale human presence in space. Before that can be accomplished, the Soviets may have to achieve success in developing a heavy-lift launcher, similar to the U.S. Saturn V, which would allow for the construction of a second-generation station out of much larger modules. A vehicle along the lines of the U.S. space shuttle to provide routine access to a near-Earth station would also be desirable, and indeed Western sources believe that the Soviets may be developing a heavy-lift, reusable shuttle that could carry twice the payload of the American craft. In addition, the Soviets have already conducted tests for a 1-tonne prototype of a 10- to 20-tonne space plane.

With such spacecraft in their fleet, the Soviets would possess both a "space truck" and a light-duty ferry vehicle to provide routine service to an expandable infrastructure in space. With this infrastructure as a hub of operations, extension of human activity to geostationary orbit, the Moon, and even Mars becomes technically feasible—indeed Soviet planners have frequently mentioned each of these as an objective. That previous U.S.S.R. efforts to reach Mars have met with failure may, in the near term, have militated against their initiating programs to send vehicles to the outer planets and deep space. But it is unlikely that the Soviets see these failures as anything more than temporary setbacks, especially in view of U.S. success in planetary exploration generally and their own success in the very difficult task of returning data from the surface of Venus—a feat that the United States has yet to match. Indeed, a Salyut space station may provide the core element of a future base necessary to ensure success of future trips to Mars.

Early Soviet Manned Spaceflight

Historical Background

A central element in the Soviet Union's exploration and exploitation of space has been its reliance on Salyut-class orbital stations occupied by cosmonauts. Seven of these stations have been officially announced by the U.S.S.R. as of December 1983. These facilities have begun to realize the possibilities envisioned by Konstantin Tsiolkovsky, the Russian scientist/engineer who is considered the founder of Soviet astronautics. Early in the century, he described how orbital stations might be built, noting that they represented the very heart of a program of space conquest.

Typical of his observations is this 1923 description of the construction of a system of Earth-orbiting stations:

> We take off in a space ship . . . and stay at a distance of 2000-3000 versts [each verst equaling 0.6629 mile] from Earth, as its Moon. Little by little appear colonies with implements, materials, machines, and structures brought from Earth. Gradually, independent production, though limited at first, will develop.[1]

Reinforcing the conviction of Tsiolkovsky, the late Leonid Brezhnev, then President of the Soviet Union, remarked in 1978:

> Mankind will not forever remain on Earth, but in the pursuit of light and space will first timidly emerge from the bounds of the atmosphere, and then advance until he has conquered the whole of circumsolar space. We believe that permanently manned space stations with interchangeable crews will be mankind's pathway into the universe.[2]

As the launch of Sputnik 1—the Earth's first artificial satellite, on October 4, 1957—opened the path toward realization of Tsiolkovsky's visions, so the Soviet Union's increasing ability to transport people into space in the 1960's, 1970's, and 1980's has added substance to Brezhnev's declaration. At least since the early 1970's, the Soviet Union seems to have taken a slow, more-or-less steady approach toward fulfilling the aspirations of its engineers and political leaders.*

Vostok

Vostok (meaning "East"), a one-seater spacecraft, was the first Soviet vehicle to carry a cosmonaut into orbit.** Six Vostoks were launched between April 1961 and June 1963; they remained in orbit for periods ranging from 108 minutes to nearly 5 days. Weighing 4.7 metric tons (tonnes) and simple in design, the vehicle consisted of two modules: an almost spherical capsule which carried the cosmonaut, and an equipment package containing fuel, life-support gear, batteries, attitude-control thrusters, and a retrorocket to slow the vehicle for reentry into the Earth's atmosphere.

Vostok's pilot was little more than a passenger. With no orbital maneuvering capability designed into the system, the pilot had few responsibilities for control of the spacecraft.

On two occasions, pairs of Vostoks flew concurrently. Two A-1 vehicles launched Vostoks 3 and 4 from the same cosmodrome within 24 hours;*** Vostoks 5 and 6 were similarly launched within 48 hours. In the second case, the Soviets showed they could launch at precise times. In 1962 and 1963, the U.S. manned spaceflight program could not match this achievement, the Mercury program being plagued by a series of "holds" and postponements.

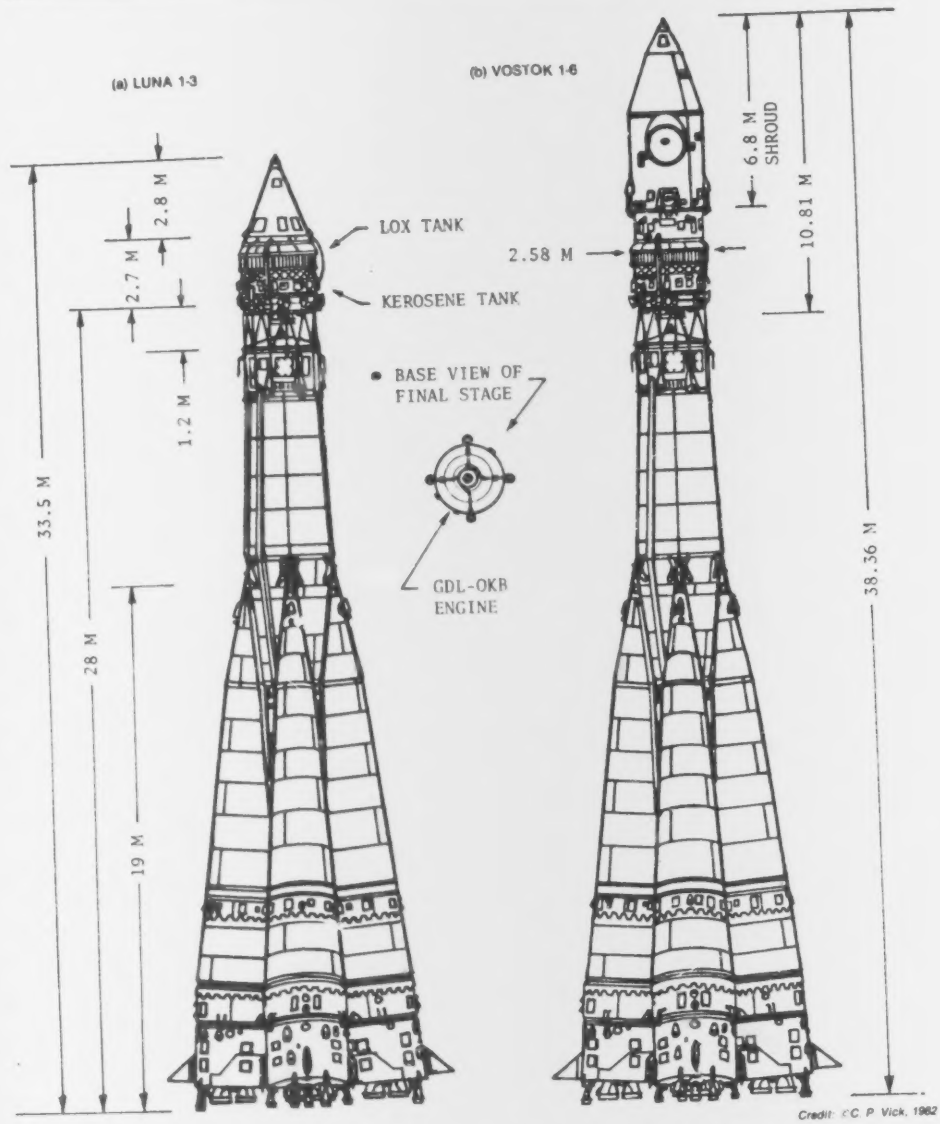
[1] K. E. Tsiolkovsky, *Collected Works*, vol. 2, Moscow, Izdatel'stvo AN U.S.S.R., 1954.

[2] Kenneth Gatland, chief author, *The Illustrated Encyclopedia of Space Technology* (London: Salamander Books, Ltd., 1981), p. 214.

*Many informed Western observers, as well as official Soviet historians and publicists, would extend this characterization to the early years of the Soviet program. Others, however, disagree, arguing that, especially in these early years, the appearance of an evolutionary course disguises a number of false starts, midcourse corrections, and radical changes of plan.

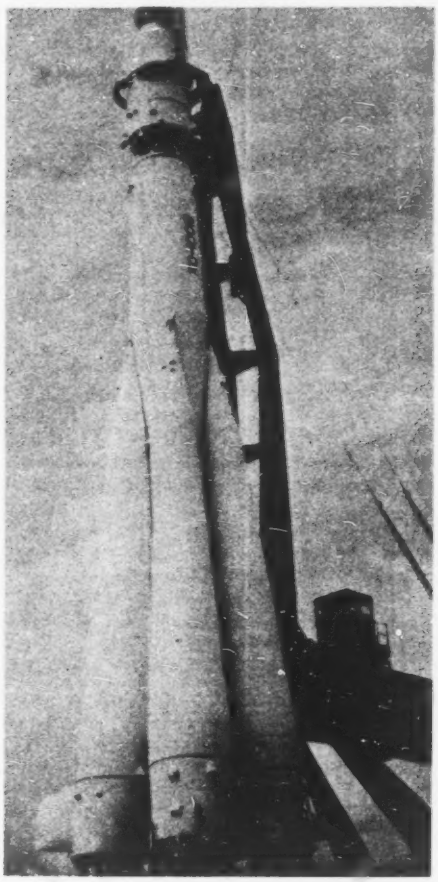
**In preparation for the first manned flight, the Soviets, in 1960 and 1961, launched at least four Sputniks with animals aboard in order to determine how they were affected by the operation of various spacecraft subsystems. These included the launch system, onboard life support and environmental control, and the reentry and recovery system.

***The designations "A," "D," "G," etc., are based on an alphanumeric classification system devised by the late Charles Sheldon of the Library of Congress. Another system designates the launch vehicle with an "SL" and a number. Thus, the "A-2" vehicle is the same as the "SL-4."



Luna 1-3 (a); Vostok 1-6 (b)—standard launch vehicle with the first type of added upper stage A-1 (a) as used to launch the first three Luna spacecraft; (b) as used to launch the six Vostok manned spacecraft

Vostok Booster



These simultaneous flights not only served as tests of ground control and launch turnaround capability, but also, as precursors of future rendezvous and docking missions, allowed a determination of how closely spacecraft could be positioned in orbit without specific orbital maneuvers. The orbital injections were so accurate that the first pair coorbited and the second passed within 5 miles of each other in noncoplanar orbits.* With these Vostok missions, the Soviets also demonstrated the capability to handle communications with two spacecraft simultaneously.

Another highlight of the Vostok program took place in June 1963 when Valentina Tereshkova became the first woman in space. Flying in Vostok 6 for 48 orbits around the Earth, she tallied more flight time than all the male astronauts in the U.S. Mercury program. Although relatively untrained and rumored to have been ill throughout her flight, Tereshkova at least achieved substantial publicity.

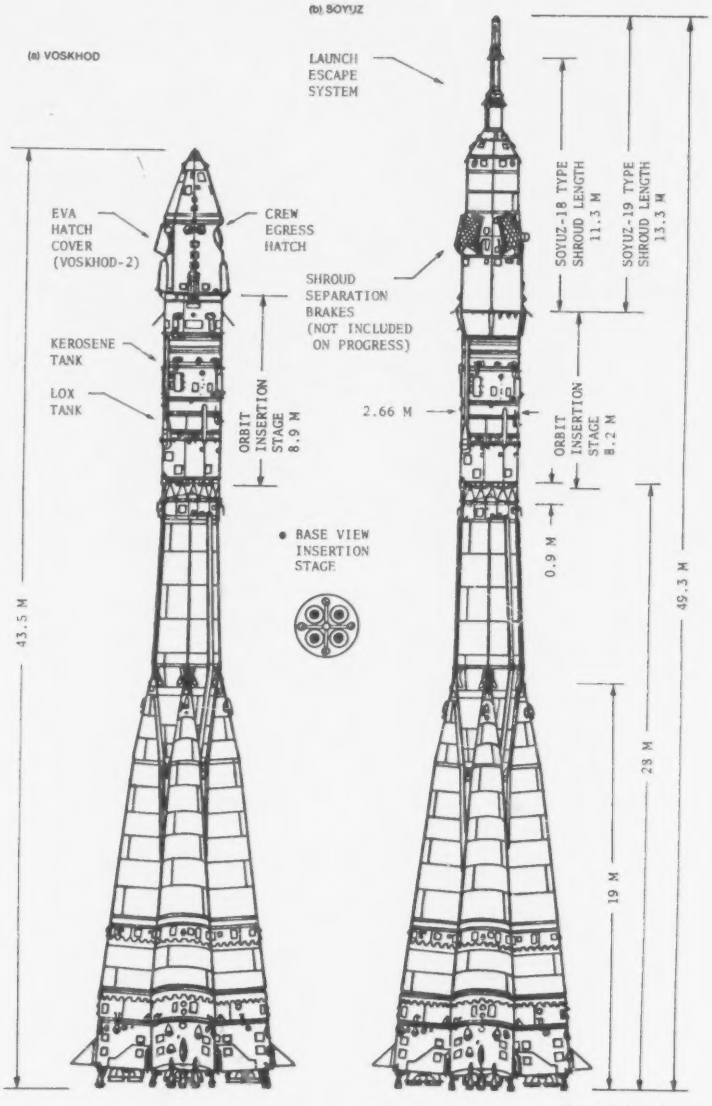
Voskhod

In October 1964 and March 1965, the Soviet Union launched the 6-tonne Voskhod ("Sunrise"), a modified Vostok capable of carrying two or three cosmonauts on daylong flights. Because the Voskhod was used only for these two flights, some Western experts believe it was intended primarily to preempt the U.S. Gemini program, which would put two astronauts in one vehicle, one of whom would "walk" in space. Voskhod had approximately the same pressurized volume as did Vostok, but more volume was made available for habitable crew space because the ejection seat and rails were removed and because the crew wore overalls instead of bulky pressurized space suits.

Voskhod 1, weighing 5.3 tonnes, had a three-person crew. In Voskhod 2, which weighed 5.7 tonnes, one of the crew couches was replaced with an inflatable airlock and associated hatches to allow for extravehicular activity (EVA), or "spacewalking." During the flight one of the crew accomplished the first spacewalk of some 10 minutes duration.** The Voskhod program included the first flight of a physician to conduct in situ observations; it also tested new TV and audio communications equipment, evaluated techniques for spacecraft orientation, and employed a new solid-rocket, soft-landing system. It did not, however,

*The orbits of Vostok 5 and 6 were in fact separated by almost 29° at their point of nearest approach, with the result that their relative velocity was approximately 12,000 feet per second. This hardly could be counted as a rendezvous.

**The cosmonaut spent a total of some 22 minutes under space conditions—12 minutes outside the spacecraft, and the preceding 10 minutes in a depressurized, inflatable airlock.



Credit: ©C. P. Vick, 1982

Voskhod-2 (a); Soyuz T (b)—standard launch vehicle with the improved upper stage A-2 (a) as used to launch the two Voskhod manned spacecraft; (b) as used to launch the Soyuz T manned spacecraft

include a launch escape system. As the first of a series of individually small but cumulatively significant advances in Soviet space capabilities, the Voskhod program brought the Soviet Union's total person-hours in orbit to some 507; by contrast, U.S. astronauts had accumulated 53 hours through Project Mercury.

By the end of the Voskhod program, the Soviet Union was dedicating its engineering expertise to the creation of a more capable spacecraft—the Soyuz ("Union"). During the 2-year hiatus between the flight of Voskhod 2 and Soyuz 1, the U.S. Gemini program of 10 flights accomplished many outstanding first-time achievements; American crewmembers also overtook their Soviet counterparts in flight time, a lead they maintained, through the Apollo-Soyuz Test Project (ASTP) in 1975, until the flight of Soyuz 29 in June 1978. The Salyut 6 missions subsequently reestablished the Soviet lead, more than double the U.S. total.

Soyuz

Building on the technical foundation laid by Vostok and Voskhod, the Soviet Union developed the Soyuz space vehicle. First flown with a pilot aboard in 1967,* Soyuz, the first of the Soviets' truly operational spacecraft rated to carry crew, remains, with evolutionary modifications, the standard vehicle for transporting crewmembers to Salyut ("Salute") space stations. The current design, called Soyuz T, was introduced in 1979. Many Western observers believe that Soyuz was initially developed to serve as part of an ambitious program to send a cosmonaut to the Moon. However, it experienced a number of technical problems, including the inability of the A-2 booster to launch a fully fueled and instrumented spacecraft, launch failures of the medium-lift Proton type D-1-e and the heavy-lift G-class boosters,** and troubles with control systems aboard automated lunar spacecraft. These problems made it impossible to use Soyuz for a manned lunar mission during the late 1960's, when beating the United States to the Moon was, presumably, of high priority. As a result, the Soviets appear to have postponed any such lunar missions indefinitely.

Why were such technical problems not overcome? The conventional explanation holds that the American lunar landings undermined the Soviets' incentive for, and interest in, putting a cosmonaut on the Moon. A fuller appraisal holds that, after Apollo 11, the planned Soviet program would have seemed second rate. The Soviets originally envisioned sending (only) one cosmonaut in a Zond spacecraft to loop once around the Moon (not to make multiple orbits) and probably required an Earth-orbit rendezvous. But the success of Apollo 8 at Christmas 1968 and subsequent near-perfect flights of Apollos 9, 10, and 11, apparently convinced the Soviets to concentrate on other activities. As alternatives that could be achieved, near-Earth, orbiting stations capable of human habitation, and automated probes for lunar sample return (via the Luna series spacecraft) and surface exploration (via Lunokhod 1 and 2) became the new foci of Soviet activities.

Carrying crews of one to three persons, Soyuz has been used to conduct a wide variety of military and scientific experiments. These vehicles are capable of orbital maneuvering, rendezvous and docking, and solo flights with crew aboard for up to 30 days.*

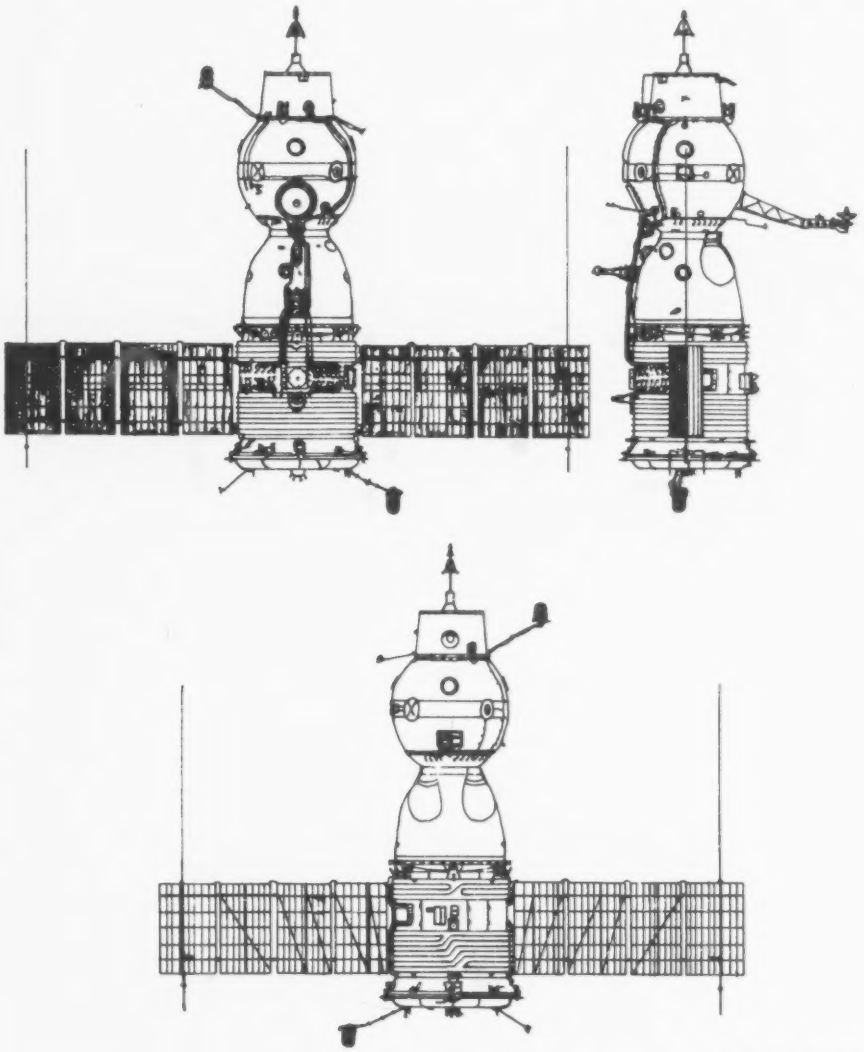
Soyuz is 7 meters in length, 2.7 meters in diameter, and up to 6.8 tonnes in weight, and contains three connected elements that are interdependent for power, thermal control, and propulsion:

- *Command Module.*—Serves as the ascent and descent compartment in which cosmonauts are ferried to and from orbit, as well as the module in which they are stationed during orbital maneuvers. It also contains system function indicators and control panels through which the cosmonauts interact with various automatic systems. The Command Module and the Orbital Work Module to-

*The first flight of the Soyuz in 1967, ended with the death of the pilot in a crash landing; this kind of craft was not flown again until October 1968.

**The G-series booster is comparable to the U.S. Saturn V vehicle.

*Although 18 days is the longest demonstrated flight of a Soyuz craft with crew aboard, the Soviets have repeatedly stated this time could be extended to 30 days. Without crew aboard, Soyuz vehicles are capable of much longer duration in orbit: Soyuz T-1 recorded a flight of 100 days while docked with Salyut 6; Cosmos 613, undocked, remained in orbit for 60 days.



Credit: C. P. Vick, 1983

Soyuz 4: The original Soyuz spacecraft. Average mass: 6,500 to 6,625 kg. Overall length from booster interface to the docking interface: 7.5 m. Body diameter: 2.2 m. Base diameter: 2.72 m. Descent module mass: 2,900 kg. The Soyuz 1-9 spacecraft were never launched fully fueled and fully instrumented. A full weight spacecraft would have weighed approximately 9,000 kg, exceeding the 7,500-kg payload capacity of the Soyuz A-2 booster

gether provide a total habitable volume of nearly 9 cubic meters (one cubic meter = 35 cubic feet), roughly twice that of Vostok; in Soyuz T the habitable volume has been increased to about 10 cubic meters. The slightly bell-shaped Command Module is a "lifting body;" its aerodynamic properties, similar to those of Apollo, are substantially better than those of Vostok, lessening reentry deceleration forces on its crew and enhancing landing zone targeting.

- *Orbital Work Module.*—Nearly spherical in shape, it allows cosmonauts to work, think, eat, relax, and sleep in surroundings that are spacious in comparison with those of the Command Module. The Orbital Work Module is also used as an airlock through which the crew may transfer to other spacecraft or embark on spacewalks; an airtight hatch is located at the interface that secures it to the Command Module.
- *Instrument and Systems Module.*—Contains a series of propulsion, maneuvering, and attitude control engines; associated fuel tanks; and a pressurized forward section holding major portions of the electronics for major operating systems (environmental, attitude control, communications, electrical, and propulsion). In some versions of Soyuz, solar cell arrays protrude, winglike, from opposite sides of this module, and provide charge and recharge of a set of internal chemical batteries. Use of solar panels ceased after Soyuz 11 but was resumed with the Soviet Union's component of the joint U.S.-Soviet Apollo-Soyuz Test Project, Soyuz ASTP,[3] and retained in the Soyuz T.

[3]For a detailed account of this mission, see, Edward and Linda Ezell, *The Partnership—A History of the Apollo-Soyuz Test Project*, in the NASA History Series, NASA SP-4209, Washington, D.C., 1978.

Pre-Salyut Soyuz Space Flights

As the core vehicle for Soviet-manned space activities since 1967, the Soyuz has accomplished diversified objectives, many of them directly related to the growth of the Salyut space station program. Capable of flying with or without crews, Soyuz has served as a test bed to observe the physiological effects of long- and short-term spaceflight on human beings (as well as animals and plants), to evaluate rendezvous and docking techniques, and to appraise Earth remote-sensing equipment and new spacecraft systems.*

In early Soyuz flights, cosmonauts exercised skills later to be integrated into operations of the Salyut space stations. Specifically, the space complex resulting from the docking of Soyuz 4 and 5 in January 1969 was described by the Soviets as "the world's first space station"[4]—a somewhat puzzling description, as there was no connecting hatch. During the few hours when the two craft were linked in power, control, and communications, two cosmonauts from Soyuz 5 donned self-contained life-support systems, left their craft through a hatch in the Orbital Work Module and, using handrails, transferred into the docked Soyuz 4. This orbiting complex provided a total working volume of 632 cubic feet, the largest attained to that date.

Although most observers contend that a true space station should allow its occupants to move from one part of the facility to another without having to resort to spacewalking, the experience gained in the Soyuz 4 and 5 complex was valuable in the design and development of larger space station configurations.

In October 1969, the Soviets launched Soyuz 6, 7, and 8. In spite of their apparent failure to dock two of the vehicles, they succeeded in flying the three spacecraft with their seven cosmonauts in coordinated, close formation. At the time, the Soviets commented that the joint exercise evaluated autonomous navigation devices for use in close-formation flying and achieved a "rational distribution" of control between man and machine.

Acting on the assumption that the construction of future space stations would require a mastery of in-space welding techniques, the Soviets included a test unit on Soyuz 6. The device was operated remotely in vacuo and manually within the pressurized Orbital Workshop Module. Three welding techniques were tried in vacuo: 1) low-pressure compressed arc, 2) electron beam, and 3) arc with consumable electrode. Only the second was reported to be a complete success. More recently, the Soviets claimed those experiments can now be "seen as an impetus to the practical development of space technology."[5]

From its first use in April 1967 to the landing of Soyuz 9 in June 1970, and the initiation of space station operations, Soyuz spacecraft flew 15 persons on eight missions for a total of nearly 44 days of operations in space. At the close of this period, Soviet personnel—on Vostok, Voskhod, and Soyuz spacecraft—had accumulated a total of some 2,550 hours in space. By comparison, the total at this juncture for U.S. Mercury, Gemini, and Apollo spaceflight was far greater, being slightly over 6,260 personnel hours.

An apparent objective of the Soyuz program was to provide a multipurpose spacecraft to be used in connection with an orbital space station. Among its many roles, Soyuz was to be a temporary base for checking out the station, a supply and transport shuttle, and a vehicle for conducting additional independent studies. Given the growing proficiency the Soviets had shown with Soyuz, there remained no major technological barriers to their Salyut space station program.

*Unfortunately, in demonstrating this latitude of functions, four cosmonauts lost their lives in two separate accidents, one in Soyuz 1 and three in Soyuz 11.

[4]This phrase was first used in a question by the Tass correspondent at the Cosmonauts' press conference in Moscow, Jan. 24, 1969. (Summary World Broadcasts, Su/2984/c/4). This same claim could have been made earlier, when two pairs of unmanned Soyuz prototypes previously achieved successful rendezvous and docking—except, of course, that some third vehicle would have been required to ferry a crew to staff them.

[5]V. Kubashov, *Pravda*, Moscow, Apr. 26, 1980, p. 3.

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Salyut Space Station Characteristics

Because each new U.S. spacecraft system is designed "from scratch," American designers tend to emphasize quantum leaps in capability. By contrast, the Soviets reuse subsystems on different spacecraft whenever possible. For instance, the same propulsion, power, and thermal-control systems may be used on many vehicles. By relying on systems flight-proved in earlier space programs,* the Soviets may have been able to reduce costs and shorten the time spent in development and construction. Still, most of these elements require modification.[6]

The Soviets are believed to have begun work directly related to the development of Salyut space stations in the late 1960's. The first in this series of stations, Salyut 1, was launched in April 1971. To date, the Soviet Union has officially acknowledged that seven of these facilities have been launched, one of which (Salyut 2) broke up in orbit. Cosmos 557, which failed in orbit, is generally thought to have been a Salyut, although the Soviets have not confirmed this inference.[7] ** Only one other spacecraft, Cosmos 382, may have been a Salyut, but the evidence for this view is meager.[8] Though the Soviets experienced numerous failures early in the Salyut program, their strategy of using flight-proved subsystems in new programs to save time and costs was less at fault than was their weakness in the quality control of these subsystems.

Salyut-class space stations utilize several distinct major components:

- *Salyut.*—An orbital laboratory, 13 meters (m; one m = 3.3 ft.) in length, 4.2 m at maximum diameter and weighing approximately 19 tonnes; it provides over 100 m^3 of usable space for up to five crewmembers. The orbits of civil Salyuts (4, 6, and 7) lie between 362 and 338 kilometers (km; 1 km = 0.62 statute mile) above the Earth's surface; those of military Salyuts (3 and 5), between 274 and 241 km; that of Salyut 1, thought to be civil, between 277 and 251 km; all have an inclination of approximately 52 °. Two of the sections—a transfer/docking compartment and a working/living compartment—are habitable; the third is an unpressurized instrument/propulsion section. Solar arrays provide power. Salyuts 1 through 5 had one docking port; Salyuts 6 and 7, two ports. With a Soyuz transport craft docked at one end and a Progress resupply ship at the other, the total length of the complex is 29 m. Onboard laboratory equipment has included a multispectral camera, materials processing furnaces, and devices for scientific, medical, and technological tests.*
- *Soyuz.*—An early model of this class of transport that was retired from Salyut operations after Soyuz 40 in 1981. This spacecraft, flown with and without cosmonauts onboard, provided a transport link for two- or three-person crews and supplies between Earth and the Salyut vehicles, or, in the case of Soyuz 22, a solo flight.**
- *Soyuz T.*—Unveiled in December 1979. The successor to Soyuz,[9] and similar to it in external shape and dimensions, Soyuz T can

*For example, the Soyuz and Salyut (1 and 4) propulsion systems were identical. Salyut 1 also used Soyuz solar panels. The propulsion unit of Molniya spacecraft was the same as that used on early lunar and interplanetary vehicles.

[6]K. P. Feoktistov and M. M. Markov, "Evolution of 'Salyut' Orbital Stations," *Zemlya i Vselennya*, September-October 1981, pp. 10-17.

[7]Nicholas L. Johnson, *Handbook of Soviet Manned Space Flight*, vol. 48, Science and Technology Series, American Astronautical Society, San Diego, Calif., 1980, p. 209. (Note that this book was published before the orbiting of Salyut 7.)

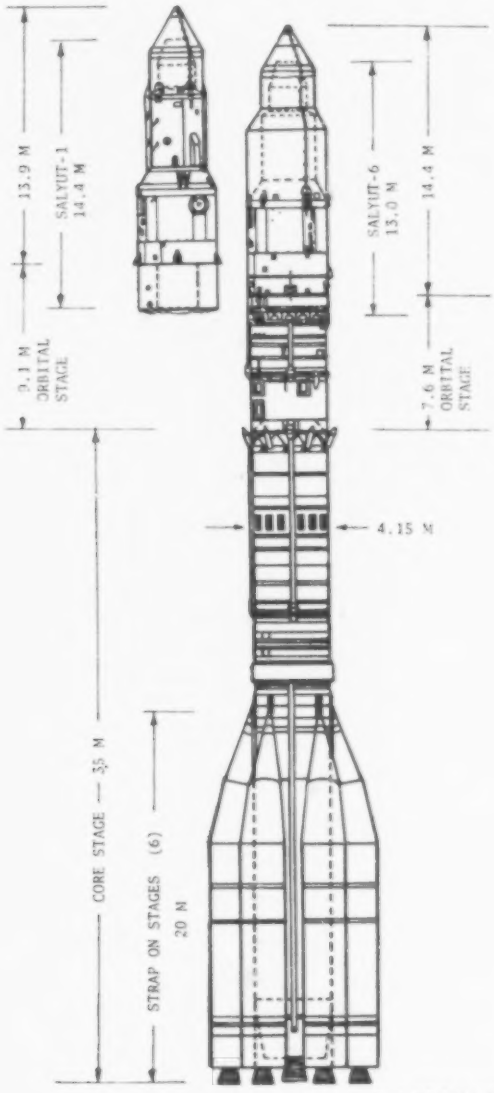
**As a rule, Soviet practice is to give a spacecraft a name appropriate to its class only if it achieves the purpose for which it was intended; craft which miscarry or are aborted receive either no name (as was the case for two that exploded in 1966) or the general appellation Cosmos. The failed Salyut 2 is the exception to this rule.

[8]Johnson, op. cit. Cosmos 382 was probably not a Salyut; it appears to have been considerably lighter and more maneuverable. Its altitude (5,000 km apogee), plane-change capability (51.6° to 55.9°), and perigee increase (from 320 km to 2,577 km) link it more probably to Cosmos 379.

*For a more detailed description of Salyut, see *Appendix A: The Soviet Salyut Space Program*.

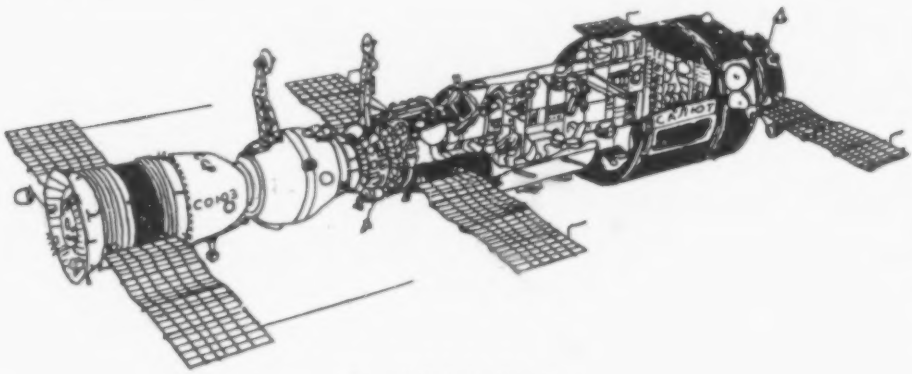
**Soyuz carried three cosmonauts on four flights. Soyuz 4 was launched with one cosmonaut, but returned carrying two cosmonauts from Soyuz 5; Soyuz 5 was launched with three and returned with one. After three crewmen on Soyuz 11 died from depressurization during reentry on June 6, 1971, cosmonauts were required to wear pressurized suits, and crew size was limited to two.

[9]Craig Covault, "Extensive Design Changes Mark Soyuz T," *Aviation Week & Space Technology* Jan. 14, 1980, p. 57.

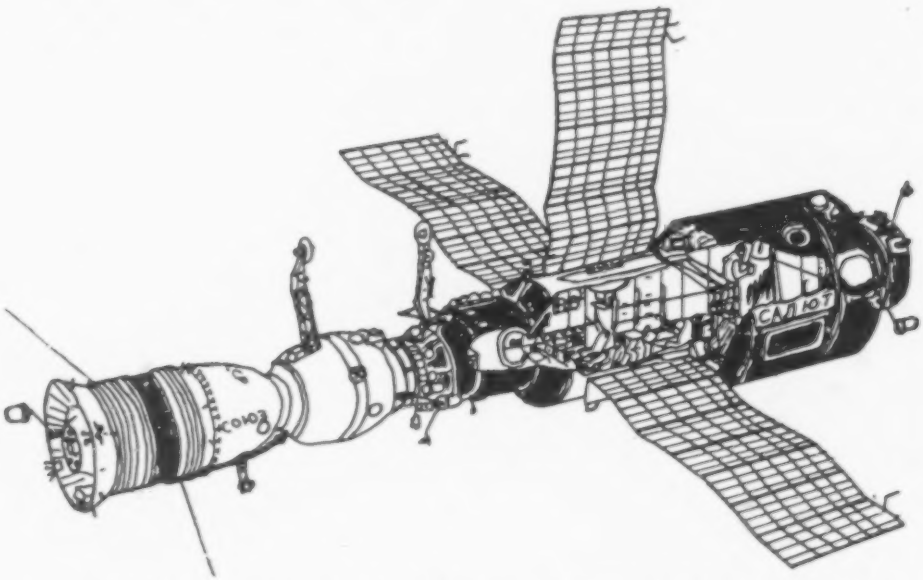


Credit: C/C P. Vick, 1982

Salyut launch vehicle: The Proton D-1 Launch Vehicle used to launch the Salyut Spacecraft Laboratory. It is a three-stage launch vehicle

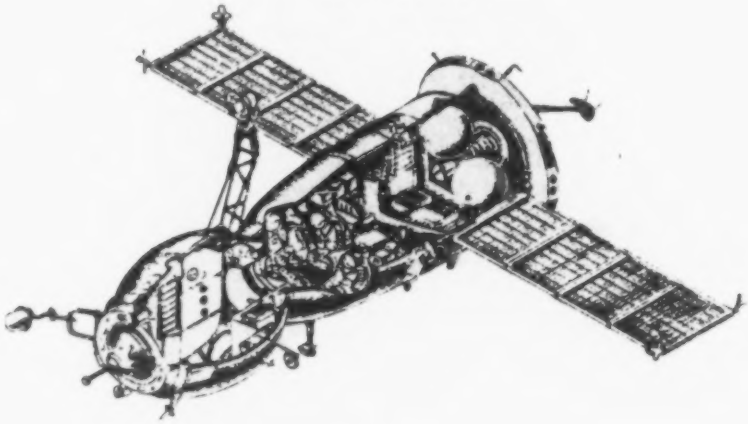


Soyuz 11 docked to Salyut 1



Soyuz 17/Salyut 4 represents a further development in the civilian Salyut Program. Major revisions are the absence of solar panels on the Soyuz ferry and the change to three large, steerable solar panels on the station

Soyuz T Spaceship



Principal Characteristics

Crew	2-3 persons
Weight	6,850kg
Weight of descent module	3,000kg
Length of the body	6.98m
Maximum diameter	2.72m
Span of extended solar battery panels	10.6m
Type of booster rocket	Soyuz

Credit: Drawing from "Mission Scientifique"
Franco-Soviétique
Saliout-7
France-USSR Scientific Mission
"Salyut-7 (Press Kit) for Soyuz T-6, 1982

transport as many as three people wearing pressure suits (or two people and a cargo pod) to the Salyuts.* Operating with solar panels, the craft sports advanced electronics and computers; it is more maneuverable than its predecessor, providing an automatic navigation control system that can be overridden for manual control, if desired. The orbital module of the vehicle, once its cargo has been unloaded into the station, can act as a container to hold used equipment and trash for subsequent destructive reentry.** The command module of Soyuz T is used to return the crew to Earth.

- *Progress.*—An unmanned transport of slightly over 7 tonnes, based on Soyuz design and using internal batteries rather than power derived from solar cells, it links to Salyut automatically, delivering equipment, parts, fuel, and other consumables.[10] The cargo capacity of Progress is about 2.3 tonnes of food, water, mail, film, equipment, and propellants. Oxygen regenerators for Salyut's life-support system are resupplied, along with gaseous nitrogen, if needed.[11] Salyut cosmonauts transfer much of this cargo into the station manually, but propellant for the station is pumped automatically. Using residual propellant, Progress spacecraft also double as space tugs, capable of pushing Salyuts into higher orbit. The last service which Progress can render to Salyut is to accept its refuse. Because it is not designed for recovery, Progress is jettisoned and destroyed upon reentry into the atmosphere.
- *Cosmos 929-Class Module.*[12]—Designed to double the habitable volume of Salyut, this module is flown without crew to the station and docked automatically. Carrying its own propulsion, guidance, and life-support systems, it is designed with several docking ports and an ejectable "sub-module" which is large enough to return the station's crew and/or heavy equipment to Earth. The first such module, Cosmos 929, was orbited July 17, 1977, and tested as a freeflyer. The next in the series, designated Cosmos 1267, docked with Salyut 6 in 1981, forming an orbital complex that flew, uninhabited, for 13 months while a variety of automated system checkouts and flight-stability experiments were carried out. The latest module of this type, Cosmos 1443 (which may weigh as much as 20 tonnes), docked with Salyut 7 in March 1983.[13] *

*Soyuz T-3, T-6, T-7, and T-8 had crews of three.

**The orbital module has not been left attached to Salyut. Without propulsion and flight control, its disposal would be difficult.

[10]K. P. Feoktistov, *Scientific Orbital Complex*. Monograph reproduced in English in Joint Publications Research Service (JPRS), *USSR Report: Space*, June 17, 1980.

[11]*Tass* in English, 0753 GMT, Jan. 24, 1978.

[12]"Soviets Show Assembly of Space Station Units," *AW&ST*, June 29, 1981, p. 21.

[13]"Soviets Launch Module to Enlarge Salyut 7," *AW&ST*, Mar. 7, 1983, p. 19.

*The long hiatus between the flights of Cosmos 1267 and 1443 can be attributed to the fact that the Cosmos 1267 test program was not terminated until the summer of 1982, at which point the Soyuz T-5 mission was already in progress.

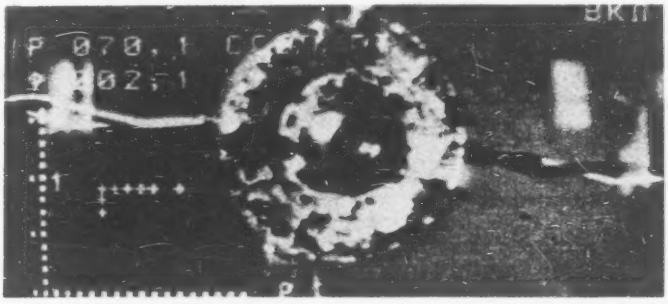
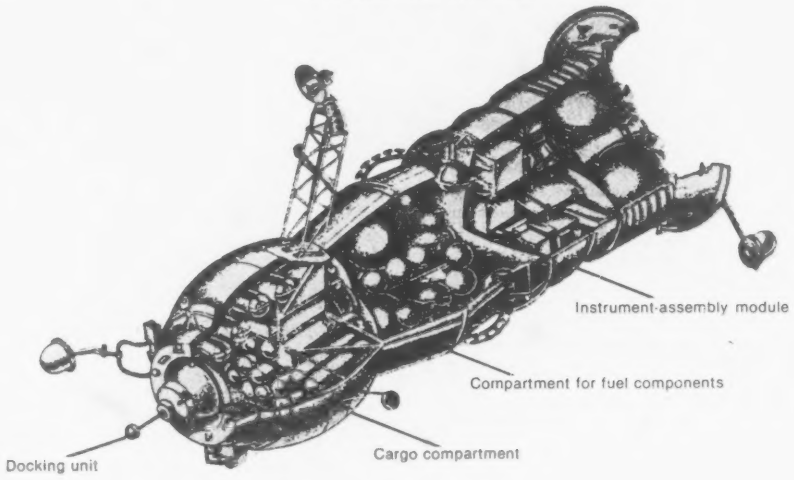


Photo credit: TASS

Link-up in Orbit: On June 28, 1983, the spaceship Soyuz T-9 linked up with the orbital complex Salyut T-7—"Cosmos-1443"

Progress Cargo Spaceship



Principal Characteristics

Weight	7,020kg
Weight of cargo delivered to the station	about 2,300kg
including:	
-in the cargo compartment	up to 1,300kg
-in the compartment for fuel components	up to 1,000kg
Maximum length	7.94m
Maximum diameter of pressurized compartments	2.2m
Type of booster rocket	Soyuz
Duration of flight:	
independent	up to 3 days
when docked with the orbital station	up to 30 days
Orbit parameters:	
height	200 to 350 km
inclination	51.6 degrees
rotation period	about 89 minutes

Credit: Drawing from "Mission Scientifique"
Franco-Sovietique
Sallout-7
France-USSR Scientific Mission
"Salyut-7 (Press Kit) for Soyuz T-6, 1982

Salyut Activities

Launch dates of Salyut space stations announced by the Soviets:[14]

Salyut 1	Apr. 19, 1971
Salyut 2	Apr. 3, 1973 (failed)
Salyut 3	June 25, 1974
Salyut 4	Dec. 26, 1974
Salyut 5	June 22, 1976
Salyut 6	Sept. 29, 1977
Salyut 7	Apr. 19, 1982

Salyut 1

The first in the Salyut series carried an Orion 1 telescope for obtaining spectrograms of stars in the 2,000 to 3,000 angstrom region of the electromagnetic spectrum; a gamma-ray telescope, called Anna III, provided observations unattainable from Earth. Several optical and multispectral cameras were used for astronomical and Earth photography. Photo sessions of geological and meteorological phenomena were coordinated with aircraft flights and orbiting weather satellites. Making use of a hydroponic farm, biological experiments centered on the effects of weightlessness on plant growth and nutrition. Long-term implications of the effects of microgravity on the human organism were also studied.

A first attempt to board the station by a three-man crew on Soyuz 10 was thwarted by faulty docking equipment on the Soyuz. A second attempt by Soyuz 11 cosmonauts was successful; this three-man crew became the world's first occupants of what some would describe as a true "space station"—i.e., long-term in-space infrastructure that accommodates human beings—residing in Salyut for 23 days. This initial success, however, was followed by an unhappy ending. A valve, intended for equalizing internal and external pressures as the spacecraft descended through the atmosphere during recovery, jerked open at the instant of the explosive separation of the command and orbital modules, permitting the cabin's atmosphere to escape. The cosmonauts, wearing no spacesuits, perished.* From then until the launch of Soyuz T-3 in 1980, Soyuz vehicles were redesigned to allow the crew to wear spacesuits. Crew size was reduced to two to provide sufficient room for the suits and related equipment. Salyut 1 was intentionally removed from orbit 175 days after launch.

Salyut 2

This vehicle did not achieve stability in orbit, began to tumble, and broke up before crews could occupy it.

Salyut 3

Unlike Salyut 1, which had two sets of fixed solar panels fore and aft, Salyut 3 carried two larger panels attached just aft of the centerbody, on the rear transfer module.[15] These panels could be rotated so the craft could continue to receive solar power whenever it was in sunlight, whatever its orientation. Salyut 3 was also modified so that its docking port was aft.[16] Other noteworthy modifications included higher efficiency power and life-support systems and more convenient interior design.

Cosmonauts aboard Salyut 3 conducted some 400 scientific and technical experiments, including high-resolution photo reconnaissance and/or Earth resources observation, spectrographic study of aerosol particles in the Earth's atmosphere, the culturing of bacteria, and the recycling of water.

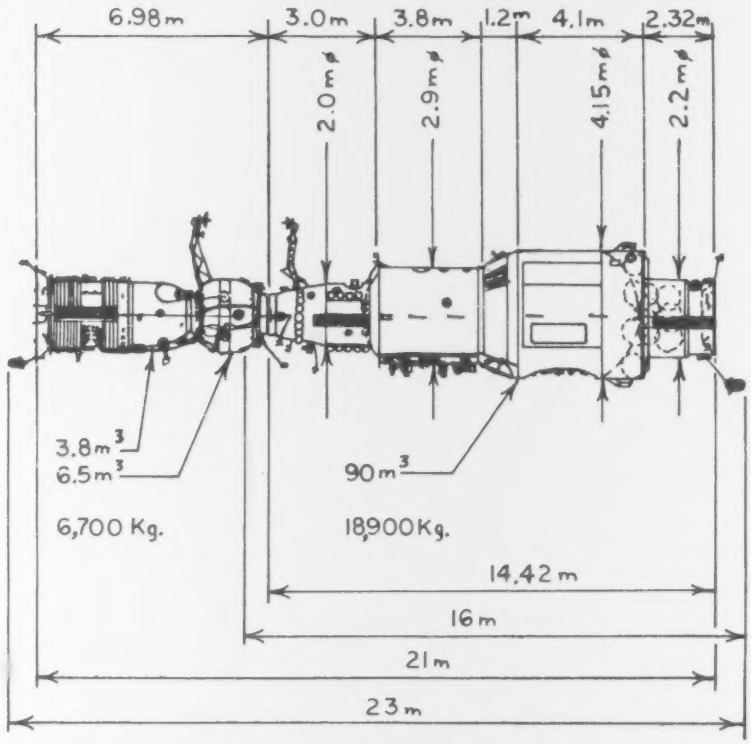
The crew of Soyuz 14 resided aboard Salyut 3 for 14 days, but a follow-on Soyuz 15 crew proved unable to effect docking. Overall, the station remained operational for twice its design lifetime. Some 2 months after Salyut 3's final crew departed, a data capsule was ejected and recovered on Earth. That only a few photographs,

[14]Cosmos 557, launched May 11, 1973, has been identified in Western circles as a successfully orbited Salyut, although the station suffered a propulsion or command-sequencer failure, rendering it useless for human occupation. The vehicle rapidly decayed in orbital altitude, reentering the atmosphere on May 22, 1973. See, "Reception of Radio Signals From Cosmos 557," The Kettering Group, *Spaceflight*, vol. 16, 1974, pp. 39-40.

*The cause of death was embolism, i.e., the formation of bubbles in the bloodstream.

[15]Although all subsequent Salyuts retained this midship mounting of solar panels, they were placed farther aft on Salyuts 3 and 5 than on Salyuts 4, 6, and 7. See, for example, *AW&ST*, Dec. 4, 1978, p. 17.

[16]Ibid.



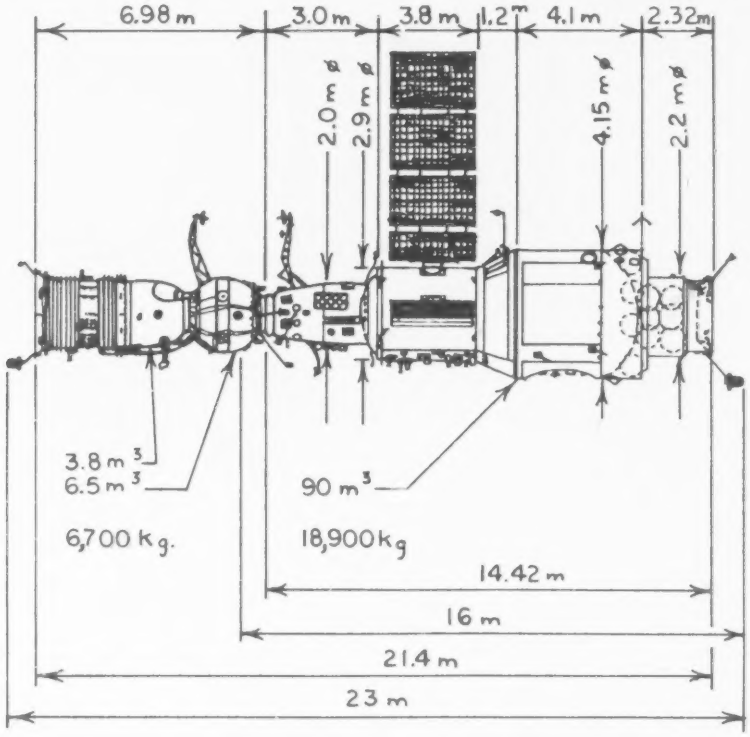
Credit ©C. P. Vick, 1983

Soyuz 11/Salyut 1. Total volume: 100.3 m³. Total weight: 25,600 kg. Total solar panel surface area: 42m²

showing noncritical interior equipment aboard Salyut 3, have been released encourages speculation that its primary mission was probably military.

Salyut 4

The design of this station, seemingly primarily civilian in character, allowed the crew more ready access for repair and replacement purposes. Two navigation systems for the station's automatic control were evaluated, as was a new teletype system. Onboard scientific equipment, weighing about 2.5 tonnes, was of much greater variety and capability than that carried on previous stations. The cosmonauts' time was devoted each day to a specific area of investigation—astronomical, Earth resources, or biomedical. X-ray, solar, and infrared spectrometric telescopes were among the host of instruments employed. Making repeated observations of agricultural patterns, forests, and maritime areas, the crew collected a large body of data on Earth resources. They also studied micro-organisms, higher plants, and the human cardiovascular system, measuring the tone of blood vessels and the circulation of blood to the



Credit: ©C. P. Vick, 1983

Soyuz 18/Salyut 4: Total volume: 100.3 m³. Total weight: 25,600 kg. Total solar panel surface area: 60 m². Solar panel span: 17 m

brain. The cosmonauts also evaluated the effectiveness of various exercise and diet regimes for counteracting the deconditioning effects of microgravity.

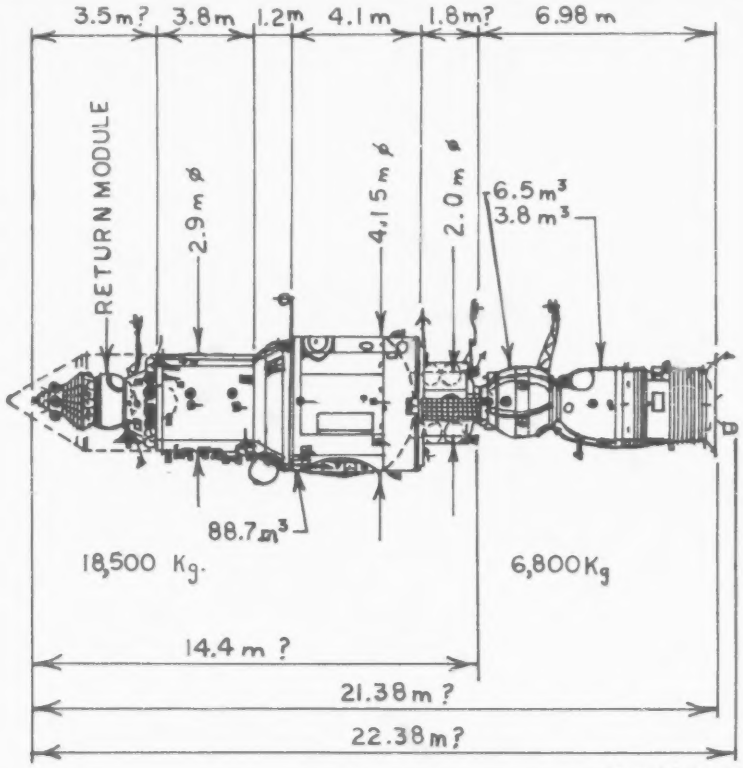
The first crew to board Salyut 4 arrived on Soyuz 17; they remained for 29 days. The mission of their scheduled successors, the crew of Soyuz 18A,[17] was aborted during ascent. Next aboard were the Soyuz 18B team; they remained on the station for 62 days. Soyuz 20, a vehicle without crew, carried biological specimens; it docked and remained at the station for 89 days before returning to Earth. Part of its mission was to determine whether Soyuz could remain without power for a relatively long time before restarting its power supply without mishap—an important consideration in planning for one crew to remain aboard a Salyut for a lengthy mission. Salyut 4 was purposely taken out of orbit after 770 days of flight.

[17] 18A is the U.S. designation. The Soviets refer to this event as the April 5 anomaly.

Salyut 5

Salyut 5, the second station thought by Western analysts to be primarily military, was the last in the Salyut series to carry only one docking port, a design characteristic which effectively prevents a resupply vehicle from docking when a crew of cosmonauts is already aboard.* Salyut 5 demonstrated a high-resolution camera, similar to that on Salyut 3, that was used to study mineral deposits, seismic areas, environmental damage caused by mud streams and railway construction paths. A device for smelting certain metals—bismuth, tin, lead, and cadmium—and a crystal growth experiment were evaluated in the station's microgravity environment. As in previous Salyuts, biological experiments on fish, plants, and fruit flies were also conducted; algae and higher order plants were cultivated to examine the effects of the spaceflight environment on their development and growth.

*It is technically possible, but too risky, to back off one spacecraft and then dock another while the crew is on board the station.



Credit: ©C. P. Vick, 1983

"Military" Salyut Conceptional Design: Total volume: 99 m³. Total mass: 25,300 kg. Total solar panel surface area (estimated): over 50 m². Total mass: over 25,000 to 25,300 kg. Only a few written descriptions, a few movie film segments, and a few photographs of the internal and external design layout of the Military Salyut 3 and 5 vehicles have been released

Over the course of Salyut 5's stay in orbit, Soyuz 21 brought a two-man crew, who remained on the station for 49 days; the crew of Soyuz 23 failed to dock; and the crew of Soyuz 24 remained aboard for 16 days.

Like Salyut 3, this station ejected a recoverable pod to Earth after its last crew departed, and, as with Salyut 3, the Soviets have released only internal photographs of limited interest. The station remained in orbit for 412 days before it was commanded to reenter.

Salyut 6

By far the most productive of Soviet space stations, this "second generation" Salyut included two docking ports, fore and aft; the station was fashioned to support a new propulsion system capable of being refueled in orbit. A water-regeneration device became a standard feature of the life-support system, supplying crewmembers with wash water; fresh drinking water was stored. Many of the experimental systems tested on earlier stations became operational on Salyut 6. A new multispectral camera (which had been flight-tested on Soyuz 22) and astronomical telescopes were flown. During its mission, cosmonauts assembled and deployed from Salyut's aft end a dish antenna used in mapping radio emissions from the Sun and the Milky Way, although the ultimate success of this experiment is in doubt.[18] Several materials processing furnaces were appraised, and infrared-sensitive semiconductors were produced. Other experiments produced superconductors, eutectics, alloys, pure metals, glass, ionic crystals, and metal oxides.[19] Salyut 6 cosmonauts also tested newly designed extravehicular spacesuits.

Cosmonauts routinely worked as in-orbit repairmen, enabling the station's design life of 18 months to be greatly surpassed. Because of the longevity of Salyut 6, perhaps to the surprise even of the Soviets themselves, its crews registered an impressive list of accomplishments. Space applications and Earth observations each accounted for about one-third of the cosmonauts' work schedule; the final third was split between biomedical studies and astrophysics.

The two docking ports permitted 33 successful dockings using vehicles with and without cosmonauts. At least two crews tried but failed to dock with the station. Five long-duration cosmonaut crews and 11 visiting crews accumulated a total of 676 days of operation. New duration records for human spaceflight were successively established: 96, 140, 175, and 185 days. During Salyut 6's lifetime, eight cosmonauts from the Soviet bloc resided in Salyut for short periods; Soyuz 33, carrying a non-Soviet crewmember, along with a Soviet pilot, failed to dock.* Salyut 6 operations introduced the use of Soyuz T and Progress vehicles, multiple-crew dockings, refueling in orbit, and the Cosmos 1267 module.**

Cosmos 1267 docked with Salyut 6 in June 1981 for a long series of what were described as checkouts of automated systems and "dynamic tests" of the overall response of the structure to maneuvers while docked with another vehicle. According to Soviet space planners, Cosmos 1267 represented a "prototype space module," built to expand the operations of future stations; such modules could be dedicated to materials processing and astronomical or other scientific pursuits, or they could be outfitted as living quarters. They could also be undocked from Salyut, flown alongside the station and reconnected. This configuration would be particularly useful for the conduct of experiments in materials processing, because it could avoid perturbations caused by the station's reactions to movements of the cosmonauts.[20]

The Soviets apparently were undecided about using their long-lived Salyut 6 for future missions,

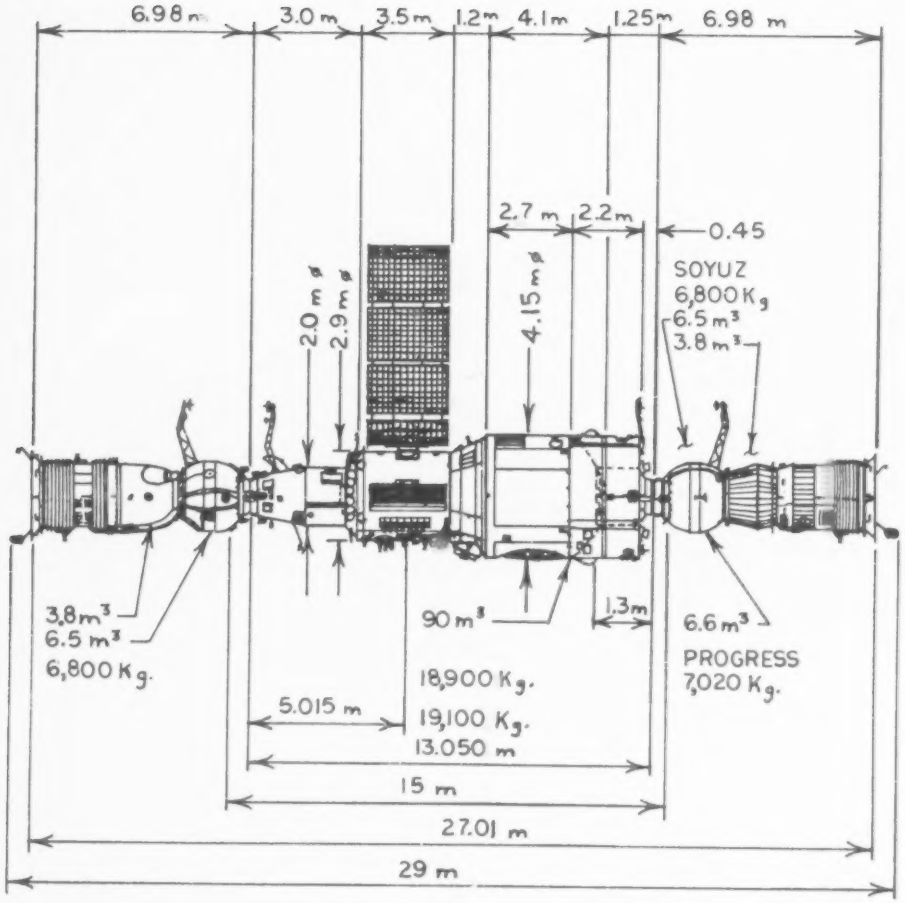
[18]Craig Covault, "Radio Telescope Erected on Salyut 6," *AW&ST*, Aug. 13, 1979, pp. 54-55. See also "Soviets Ready Salyut 6 Crew Return," *AW&ST*, Aug. 13, 1979, p. 21.

[19]James C. Brown, *Materials Processing on the Soviet Salyut 6 Space Station*, Memorandum SWM81-10041, Central Intelligence Agency, National Foreign Assessment Center, Apr. 1, 1981. Soviet research in the materials processing-in-space arena appears extensive. According to MIT professor Harry Gatos, before a House space subcommittee review of space processing, a large new Soviet research institute employs several hundred full-time scientists working on space materials processing. Other countries involved in this institute include Poland, Hungary, Czechoslovakia, and France. See *Astronautics and Aeronautics*, September 1979, p. 9.

*Soyuz 25 with two Soviet crew also failed to dock with Salyut 6.

**There was no crew aboard either Cosmos 1267 and Salyut 6 during their docking of 40 days, after which both were deorbited.

[20]*From Sputnik to Salyut: 25 Years of the Space Age*, Novosti Press Agency Publishing House, 1982, passim.



Credit: C. P. Vick, 1983

Salyut 6 and attached transport vehicles Soyuz and Progress in various combinations; diagram shows, left to right, Soyuz, Salyut and Progress: Total mass with two Soyuz: 32,500 to 32,600 kg. Total mass with one Soyuz and one Progress: 32,720 to 32,770 kg. Total mass with one Soyuz: 25,700 to 25,750 kg. Total volume with two Soyuz: 110.6 m³. Total volume with one Soyuz and one Progress: 106.9 m³. Total volume with one Soyuz: 100.3 m³. Total solar panel surface area: 60 m². Solar panel span: 17 m

and twice had Cosmos 1267 boost the complex into a higher orbit. After Salyut 7 was launched, Cosmos 1267 propelled Salyut 6 into a destructive reentry on July 29, 1982. The stay of Salyut 6 in orbit lasted 4 years and 10 months.[21] [22]

Salyut 7

Currently, the Soviet Union is maintaining Salyut 7 in orbit. Soviet space officials indicate it is similar in size and shape to its predecessor.[23] [24] Two docking ports are again provided, one of which has been modified to handle larger spacecraft. The standard station control system on Salyut 7—the result of experiments conducted on other stations—allows its crews to operate the facility in more automatic modes.[25] Recommendations from cosmonauts who had lived aboard Salyut 6 led to an interior "modernization program" to make Salyut 7 more livable. Designers have taken special care to protect certain observation windows, shielding both inside and outside panels with removable covers, because contaminants from propulsion unit firings, as well as impacts from micrometeorites, degraded the windows on Salyut 6. The color scheme was changed to improve the residential and working environment, and a refrigerator was installed.

Salyut 6 carried a submillimeter wavelength infrared telescope; Salyut 7 contains a complex of X-ray equipment. The first long-duration crew

[21] Peter Smolders, "Saluting Salyut's Space Record," *New Scientist*, Oct. 11, 1979, pp. 118-121.

[22] "TASS Reports Termination of Flight of Salyut 6 Station," *Pravda*, July 30, 1982, p. 1.

[23] B. Konovalov, "A Trip Through the 'Salyut 7,' " *Izvestiya*, May 18, 1982, p. 3.

[24] "The New 'Salyut 7' is a Modernized Station," *Air and Cosmos*, No. 910, June 5, 1982, p. 43.

[25] "Salyut 7 Incorporates State-of-Art Upgrades," *AW&ST*, July 26, 1982, pp. 26-27.

Crewmen on Station Aboard Salyut 7

used a new computer-controlled 300-lb materials-processing furnace to produce several pounds of semiconductor monocrystals. This furnace operates automatically when the station is unoccupied. New systems for medical examination and diagnosis have improved the range of biomedical parameters that can be monitored, either onboard by the cosmonauts or remotely from the ground. For example, a thorough electrocardiogram can be obtained automatically. Measurements of blood circulation in the cerebral cortex, an important parameter in near-weightless conditions, are receiving particular attention.

Performing about 300 experiments, the station's first long-term crew worked to meet orders from 500 national economic and scientific centers. Soviet officials stated that, for the first time, a Salyut space station undertook "direct research production tasks."[26] Some 20,000 photographs of the Earth's surface were reportedly taken during the first phase of this operation.

Initial operations of Salyut 7 relied on Progress vehicles for resupply and refueling.[27] The Soyuz T-5 transported a crew of two to the Salyut in May 1982. Subsequently, a Soyuz T-6 with three aboard, including a French spationaut, and a Soyuz T-7 with three, including the world's second woman cosmonaut, visited the primary crew on separate occasions. The primary crew set a new world endurance record for spaceflight: 211 days.

On March 2, 1983, "a modular transport ship," Cosmos 1443 (a Cosmos 929-class module), was launched, and docked with Salyut 7 on March 10 in a configuration similar to the Salyut-6/Cosmos-1267 complex.[28] Although a Soyuz craft with a crew of three aboard failed to dock with the complex in April 1983,[29] a two-person crew boarded the station on June 28, 1983, and remain aboard as of this writing.

Photo credit: Novosti

Members of the Soyuz-9 space mission

The Salyut-7/Cosmos-1443 orbital complex was thought capable of housing as many as six crewmembers.* Stationing of that many people aboard the complex would have born out earlier Soviet pronouncements that this configuration was a prototype for future larger scale space stations. On August 14, 1983, Cosmos 1443, along with its descent module (with a capacity for returning one-half tonne of cargo, but not a crew member) was undocked from Salyut 7.** Then on September 19, 1983, Cosmos 1443 was inten-

[26] "Kuznetsov Presents Awards to Salyut 7 Cosmonauts," Moscow Domestic Service, LD291458, Dec. 29, 1982.

[27] In the early phase of Salyut 7, two small "subsatellites" were launched from the station by its first long-duration crew. These satellites, Iskra 2 and Iskra 3, were constructed by students of a Moscow Aviation Institute and served as communications satellites for amateur radio enthusiasts. The two satellites were "launched" from the station's airlock. For a detailed account of early work on Salyut 7, see: "Salyut Mission Report," by Neville Kidger, *Spaceflight*, January 1983, pp. 28-29.

[28] "Soviets Launch Module to Enlarge Salyut 7," *AW&ST*, Mar. 7, 1983, p. 19.

[29] "Soviet Docking in Space Fails; Mission Aborted," *Washington Post*, Apr. 24, 1983, pp. A-1, A-12.

*It is not clear that docking arrangements allow more than one Soyuz T to dock with a Salyut 7/Cosmos 1443-type combination at a time; such a provision would be expected in the future.

**A rather complex sequence of events occurred during August 1983. Cosmos 1443 undocked on August 14. Then on August 16, Soyuz T-9 undocked, the Salyut was rotated through 180°, and the

The crew of the Soyuz T-7 spaceship (from left to right)—crew commander Leonid Popov, Pilot-Cosmonaut of the U.S.S.R.; researcher engineer Svetlana Savitskaya; and flight engineer Novosti

tionally deorbited, perhaps because of a serious malfunction affecting its operation.[30] More recently, Salyut 7 itself has experienced a serious propellant leak, leaving it with two of its three oxidizer tanks empty and 16 of its 32 attitude control thrusters unusable. Because of the difficulty of making repairs, it is less likely that Salyut 7 will become a major component of a large modular station.

Military Utility of Salyut

Salyut space stations serve both military and civilian needs.[31] Through the mid-1970's, each station could be distinguished as military or civilian by its design, communications frequencies, orbits, onboard equipment, and crew composition. Such distinctions are virtually impossible to draw for the Salyut 6 and 7 stations. Indeed, now that 6 years have passed since the last Salyut clearly identifiable as military was used, a separate military Salyut program may no longer exist.

Civilian Salyuts (1 and 4) were flown in higher orbits, increasing their value for astronomical observations. Telemetry was typical of Soviet nonmilitary spacecraft, and the crew commander, although usually from the Soviet military, was accompanied by a civilian flight engineer.

In contrast, military Salyuts (3 and 5) were flown in lower orbits, presumably to get the most out of the capabilities of onboard photo reconnaissance assets and activities which replaced the astronomical activities of civilian flights.* Flights of these Salyuts, typically using radio frequencies

Soyuz was redocked at the "front" end of the station. On August 17, Progress 17, bringing additional fuel, air, and water was docked to the "back" end of the station. On August 19, the descent module from Cosmos 1443 landed in Kazakhstan, U.S.S.R. Since the undocking of Cosmos 1443 and Salyut 7, the two spacecraft went out of and (through firing of th.; motor of the Progress attached to Salyut) came back into orbital phase, but apparently no attempt was made to redock prior to the intentional deorbiting of Cosmos 1443.

[30] *Aviation Week & Space Technology*, Oct. 10, 1983, p. 25.

[31] Johnson, op. cit., pp. 213-217.

*In order to maintain such a low orbit for very long, large quantities of propellant must be expended.

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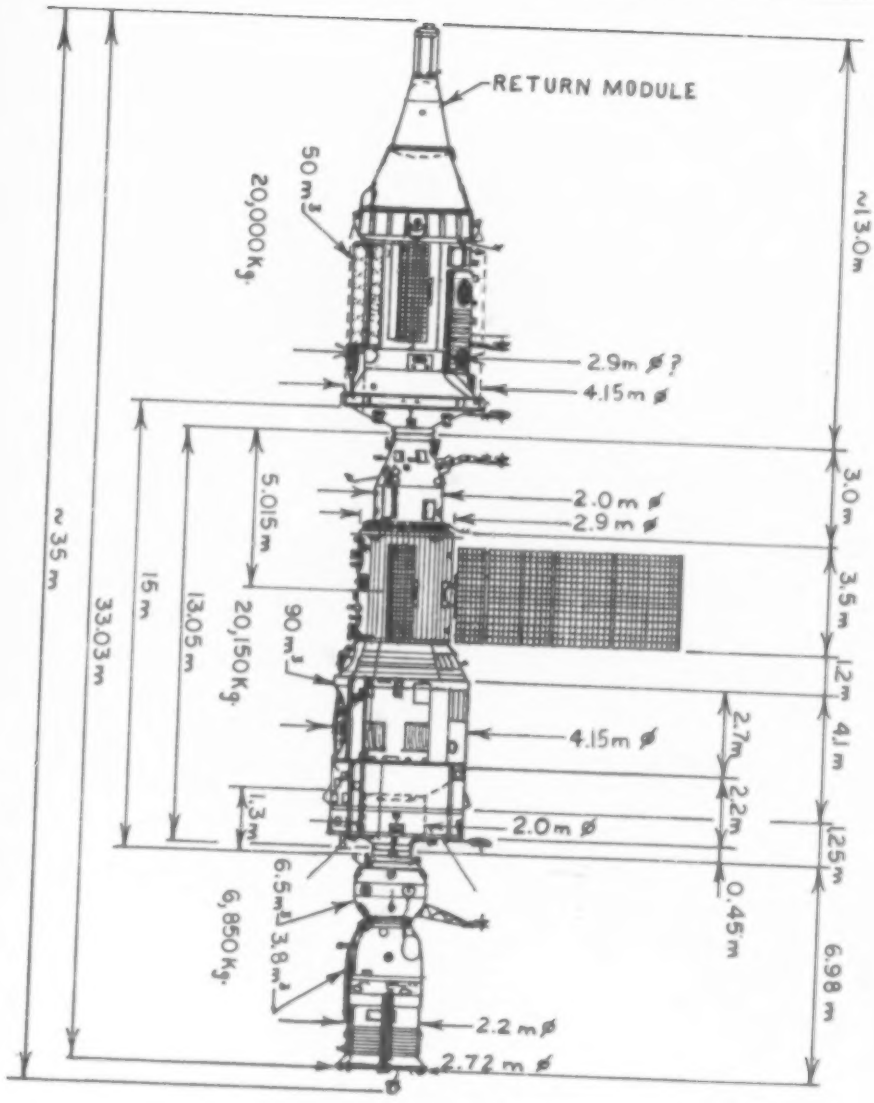

Credit: E.C. P. Vick, 1983

Cosmos 1443/Salyut 7/Soyuz T: Total mass: about 47,000 kg. Total solar panel surface area: 100 m². Total power output: 7 kW. Total volume: 150.3 m³. Solar panel span: 16-17 m

associated with other Soviet military space missions, were conducted by all-military crews. They remained in orbit for shorter periods than their civilian counterparts and ejected capsules for recovery on Earth.

Of course, there must be some military interest in scientific programs. For instance, astronomical investigations completed by Salyut crews maintained the orientation of certain equipment to an accuracy of a few arc-seconds, a capability related to what might be needed to aim directed-energy weaponry. The materials processed in microgravity could range from electronic components to new pharmaceuticals.

Many activities aboard Salyut might be described, in the United States, as civil, but others might well have military implications. Whether military activities aboard these stations pose a serious, near-term threat to the United States cannot be determined from the open literature. Certain military operations may have been turned over to automated spacecraft: Soviet advancements in satellite photo reconnaissance may have reduced the need for crewmembers to gather these data.

Comparisons with the U.S. program are also complicated by the fact that no operational requirements for U.S. military missions aboard a space station, particularly those requiring crewmembers, have been formally stated.[32] However, in view of President Reagan's speech in March, 1983, on the subject of defense against ballistic missiles, this assessment may be changing.[33] In any case, the military value of the Soviet space station remains open to question.

Capability Base for Salyut Program

The Soviet technology base must inevitably affect its space program. A thorough appraisal of this base cannot be obtained because the Soviets tightly control what information about the program is made public. Observers, however, have noted these characteristics:[34]

- *Simplicity.*—Compared with similar Western systems, Soviet components are, in general, relatively less complicated.
- *Commonality.*—Once a basic system or subsystem is developed, it is used as much as possible thereafter. With this approach, a relatively narrow technological base can serve much broader needs.
- *Gradual Change.*—This principle derives from the other two. Because each system is closely related to its predecessor, the risks attendant on innovation are reduced.

In sum, the Soviets prefer to use a single, reliable basic design over a relatively long time in order to provide several generations of systems for similar or related uses.

Professional surveys of industrial technology in the U.S.S.R. suggest that the Soviets are generally unwilling or unable to undertake rapid innovation. In some cases, however, a few critical suppliers and supporting industries have been able to set priorities that led to rapid change.

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[32] At the Space Station Symposium held in Washington, D.C., in July 1983, Richard DeLauer, Undersecretary of Defense for Research and Engineering, reiterated this position. For an earlier discussion, see: Joel Levy, et al., "Potential Military Applications of Space Platforms and Space Stations," *Eascon 82, 15th Annual Electronics and Aerospace Systems Conference, IEEE Conference Record 82CH1828-3*, Sept. 20-22, 1982, pp. 269-276. This paper states: "It is apparent that, at this time, the DOD has not defined any firm requirements for space platforms or space stations." The military utility of a manned space station, say for photo reconnaissance, requires detailed tradeoff studies. " . . . in order to evaluate whether the increase in system performance due to man's presence warrants the increase of approximately an order of magnitude in the cost of the program. Any increase in system performance achieved by such means would be measured by some, as yet undefined, weighing of factors such as cost, risk, survivability, reliability, threat recognition and the time to respond."

[33] "President Seeks Futuristic Defense Against Missiles," *Washington Post*, Mar. 24, 1983, pp. A-1, A-13. See also, "Reagan Plans New ABM Effort," *Science*, vol. 220, Apr. 8, 1983. More recently, the Defensive Technologies Study Team, headed by former NASA Administrator James C. Fletcher, has been reported as concluding that "a space-based [ballistic missile defense] system may also require a continuous manned space presence . . . Both cost and effectiveness may justify manned systems . . . Development of a repair and refurbishment system may be the key to operational and economic viability of space-based ballistic missile defense." *AW&ST*, Oct. 24, 1983, p. 50.

[34] Herbert P. Ely, "Impact of the Technology Base on Soviet Weapon Development," *Army Research, Development & Acquisition Magazine*, May-June 1982, pp. 12-13. For a broader look at conditions of Soviet technology see: *Industrial Innovation in the Soviet Union*, Ronald Amann and Julian Cooper (New Haven, Conn.: Yale University Press, 1982). The authors discuss Soviet military technologies in detail, and conclude that they do not have the quality and level of sophistication that those of the United States have. In general, although Soviet industry is slow to respond to new R&D initiatives, the technology lag is smallest in the defense and space sectors.

Hampered by a lack of precise instrumentation and sophisticated engineering techniques, Soviet space designers frequently take a "brute-force" approach to problem-solving.[35] Although this approach has obvious drawbacks, it does tend to impose—in contrast to the U.S. system of single-unit production—an economy of operation through the exploitation of continuing production of less complex hardware. Lastly, there is a consensus that an uneven research and development base, poor quality control, and poor quality assurance has impeded Soviet space development on many fronts.[36]

Evidence for these evaluations is provided by the mixed results from lunar probes and interplanetary exploration. Crossing the relatively short distance to Earth's neighboring Moon, Soviet vehicles were generally successful in achieving soft landings, trekking across the lunar terrain, and returning samples of the Moon's surface directly back to Earth. Four-month dashes to the planet Venus resulted in significant Soviet success in landing vehicles and operating their sensors for brief periods on the surface of that extraordinarily inhospitable world.

By contrast, 9-month journeys to Mars have met with repeated failure, and no attempts have been made to probe Mercury, Jupiter, and Saturn. The outer planets in particular, the subject of intense scrutiny by U.S. space vehicles, have so far remained beyond the reach of Soviet probes. The rather limited time during which important systems aboard Soviet spacecraft remain operational is still a major limitation. This weakness also appears in spaceflights with Soviet crews, who have been able to keep Salyuts operational by undertaking unscheduled maintenance and repair.

As these operations of Soviet spacecraft are reviewed, certain limitations become apparent:

Salyut.—Although Salyut is smaller than currently proposed U.S. concepts, it has accommodated Soviet crews for as long as 211 days. Attachment of a Cosmos 929-type module should markedly improve living conditions.

Salyut cannot communicate via line-of-sight circuits directly with Earth stations (in the Soviet Union) during every one of its 15 or 16 daily orbits. On those orbits when communication is not possible, the cosmonauts sleep, and telemetry, communicated *via* shortwave circuits, is sometimes used to monitor basic onboard systems. Even during the in-contact orbits, the crew can communicate with Earth stations on Soviet territory for only 25 minutes out of every 90.

Compared with scientific equipment proposed for any future U.S. "stations," Soviet scientific equipment is low in weight and used sporadically: just a small portion of it is replaceable. The station itself can generate 4 kW of power, Cosmos 1443 contributed 3 kW from its own solar panels while it was attached to Salyut, and additional modules may be expected to do likewise. The low return-weight of equipment transported back to Earth via Soyuz T is one constraining factor; because of the delay in returning photographic film to Earth, its use, rather than reliance on advanced electronics, for remote sensing of the Earth is another (although the installation of live television transmission equipment aboard the latest Salyut has partially overcome this limitation).* The life-support system requires regular deliveries of drinking water and supplies for purifying the cabin atmosphere.** The current configuration requires that Salyut be refueled through its aft docking port.[37]

Soyuz T.—This vehicle, like the original Soyuz, is a reliable, though relatively unsophisticated, spacecraft. Its onboard computer has no backup. The latest mission of cosmonauts aboard Salyut 7 demonstrated an operational lifetime of Soyuz T, while attached to the station, of 150 days. Be-

[35]Ursula M. Kruse-Vaucienne and John M. Logsdon, *Science and Technology in the Soviet Union—A Profile* (Washington, D.C., Graduate Program in Science, Technology and Public Policy, The George Washington University, 1979), pp. 3-7.

[36]Even though impediments exist, can they be circumnavigated by a concentrated scientific thrust? See, for example: John W. Kiser, III, "Technology: We Can Learn a Lot From the Soviets," *The Washington Post*, Aug. 14, 1983, pp. C1, C4. See also: Malcom W. Browne, "Soviet Science Assessed as Flawed But Powerful," *The New York Times*, May 20, 1980, p. C-3, which describes the buildup of the Soviet science work force and its potential for scientific surprise.

*App. A.

**Some water is recycled aboard Salyut, a capability that U.S. spacecraft do not possess.

[37]For a discussion of rendezvous and docking techniques involving Soyuz T and the Salyut stations, see: *Aviatsiya i Kosmonautika*, 1979, pp. 36-39, translated in JPRS 74805 Space No. 1, Dec. 20, 1979.

cause the Soviets are reluctant to land Soyuz T in the water or at night, they impose strict constraints on the duration and scheduling of its flights. Yet, they have repeatedly demonstrated the ability to deviate from these conditions when necessary. No spacecraft, of course, can land without restrictions. Indeed, the U.S. Space Shuttle Orbiter operates with even greater restrictions than Soyuz. Major modifications of the U.S. craft would be required if its staytime in orbit were to approach that of Soyuz T.

General

In order to minimize one of these deficiencies, the Soviet Union, according to a plan lodged with the International Frequency Registration Board in 1981, intends to operate a system called the Eastern Satellite Data Relay Network (ESDRN), which will employ radiofrequencies similar to the U.S. Tracking and Data Relay Satellite System (TDRSS). The Soviet system would allow reliable, nearly continuous communication with Salyut stations and other spacecraft in low-Earth orbit, commencing perhaps as early as December 1985.

Despite the fact that the Soviet technology base advances more slowly and still remains, in most instances, less sophisticated than that of the United States, it is not suggested that these factors seriously inhibit what appears to be a continuing and expanding set of objectives for productive operations in space, made possible, in part, by people aboard Salyut-class facilities, and determined by what the Soviets consider valuable. Resupply, repair, and service functions, for example, are often performed by cosmonauts, who were a key factor in the longevity of Salyut 6. The Soviets regard the adaptability of human beings as a form of insurance that permits continuous and variegated space station operations.[38]

Whereas the U.S. program from its inception was heavily influenced by the high visibility of the Apollo program and the continuing presence of test pilots, who insisted that astronauts be "in the loop" whenever possible, the Soviet program at the outset was heavily influenced by the Institute for Automatic Control, which obviously had a different orientation. However, the same unreliability of automated equipment that has plagued the Soviets' long-duration planetary probes has made the human presence an essential element in the Salyut program. As a result, the Soviets have gone far in discovering how the attributes peculiar to human beings may be put to effective use in conducting unforeseen as well as planned activities in the course of maintaining and operating a space station.[39] Their growing fund of experience supports and in turn is supported by two related requirements of their ideology and their judgment of their national security interests: that they begin "the inevitable socialist expansion into space," and that they maintain and enhance their national prestige. These factors have resulted in what should be appreciated as the cultivation of the human presence in space.

The Soviets have claimed that people stationed in space can improve the effectiveness of Earth observations. After a period of adjustment of a few weeks, cosmonauts report both improved visual acuity and enhanced perception and differentiation of color, making it possible for them to identify land features and ocean phenomena (e.g., the presence of schools of fish) that were not expected to be visible from low-Earth orbit. These findings have been pursued in real-time aboard Salyut space stations.[40,41]

In support of the human presence, the Salyut stations have served as medical laboratories in which the occupants have completed comprehensive programs of biomedical and life-science research. Much of this data-gathering is dedicated to answering the following questions: Do long spaceflights result in unacceptable psychological effects and produce harmful physiological alterations of the human body? If so, can these effects be countered? In search of answers, the Soviets

[38] G. T. Beregovoy, et al., *Experimental Psychological Research in Aviation and Cosmonautics* (Moscow: Navka Press, 1978).

[39] G. T. Beregovoy, et al., "Research in Space Psychology," *Psikhologicheskiy Zhurnal*, 3(4), July-August 1982, pp. 160-167. (In English, JPRS *Space*, Nov. 19, 1982, pp. 17-30.)

[40] Jerry Grey, *Beachheads in Space: A Blueprint for the Future*, New York, 1983, p. 42.

[41] Personal communication from Chris Dodge, Science Policy Research Division, Congressional Research Service, Washington, D.C., *re* U.S.-U.S.S.R. Working Group on Space Biology and Medicine, meeting of November 1981, Uniformed Services University of the Health Sciences (USUHS), Bethesda, Md.

are planning in-flight missions that would entail stays up to 1 year for cosmonauts.

Special exercise and diet regimes are being employed to counter changes in cardiovascular tone and muscle systems during flight and to facilitate the subsequent readaptation to gravity. Some changes such as the loss of red blood cells have been found to be self-limiting and subsequently reversible. Others, although decreasing in rate over time, may not entirely level off. In particular, osteoporosis, the loss of calcium from bone, may pose a formidable problem in the context of flight durations of a year or more in the absence of gravity.[42] [43] Extensive ground-based studies employing simulations of weightlessness (including bed rest and water immersion) are augmenting inflight research.[44]

Medical studies of the cosmonauts, supplemented by onboard diagnostic equipment to monitor their overall health on long flights, continue to be given a high priority aboard Salyut. Certain countermeasures have been designed to maintain good health and high performance during prolonged spaceflight. The most demanding of these is exercise, which consumes an average of 2.5 hours during each day in space and involves the use of specialized gear as well as conventional exercise devices.

The Soviets have devised a comprehensive psychological support program, including the transport of letters and news to Salyut crews and frequent two-way video communication with families and research counterparts on the ground. These measures have been instituted to counter the cosmonauts' isolation and heavy workload.

One challenging goal is a closed life-support system aboard Salyut that would generate water and air and produce food, independent of external supply.[45] [46] A complete growing cycle of higher order plants has been evaluated aboard Salyut, as has control of plant diseases and use of vegetables and herbs as food for human consumption.* Creation of partially closed ecological systems may conceivably lead to completely closed systems, suitable for flights of 2 years or more. Designed in accordance with biomedical information derived from past Salyut flights, these closed systems could be implemented for eventual flight to the Moon and neighboring planets; such systems might also lead to substantial cost reductions in Earth orbit operations.

[42] Arnauld E. Nicogossian and James F. Parker, Jr., *Space Physiology and Medicine*, BioTechnology Inc., NASA Headquarters contract NASW-3469, Washington, D.C., September 1982, pp. 20-24.

[43] The Soviets themselves seem undecided about whether very long-term weightlessness will be a general problem. Cosmonaut Georgi Gretchko is quoted (in "Soviets Unveil Space Station Plans," by Peter Smolders, *New Scientist*, June 30 1983, p. 944) as saying of a possible trip to Mars: "Your heart and entire organism would have become so accustomed to living in space that you would never be able to stand life on Earth again." On the other hand, see Grey, op. cit., pp. 41-42: "One of the cosmonauts, Valery Ryumin, spent a full year in space (he served on the 175-day and 185-day flights aboard Salyut 6), and was in excellent physical condition after both flights. He walked comfortably only one day after returning to the oppressive [*sic*] gravity of Earth, and was jogging happily on the third day. After exhaustive studies of the returned cosmonauts, the Soviets' bioastronautics mentor Oleg Gazenko concluded, 'I believe that humankind can be as happy in space as on Earth.' "

[44] Arnauld E. Nicogossion and Courtland S. Lewis, *A Critical Review of the U.S. and International Research on Effects of Bedrest on Major Body Systems*, Biotechnology, Inc., NASA Headquarters contract No. NASW-3223, Washington, D.C., January 1982.

[45] I. I. Gitelson, et al., *Closed Ecosystems as the Means for the Outer Space Exploration by Men (Experimental Results, Perspectives)*, IAF-81-164, presented in Rome, Italy, Sept. 6-12, 1981.

[46] Y. Y. Shepelev, "Biological Life-Support Systems," ch. 10 of *Foundations of Space Biology and Medicine*, vol. III: Space Medicine and Biotechnology, M. Calvin and O. G. Gazenko (eds.), NASA, 1975. NASA SP-374, pp. 224-308.

*Borage was grown from seedlings to leaf stage, and spring onions from bulbs to maturity.

Future Directions

The Soviet Union's Salyut space stations have formed the backbone of an ambitious and expansive program involving human beings in space. The ideological underpinning of Salyut is the desire to project and maintain an image of scientific, technological, and industrial world leadership in space. Overall, the Soviet approach toward implementing these goals has been one of cautious advance—a step-by-step evolution consistent with an often-stated, long-term goal of spreading Soviet influence into near-Earth space and beyond. As was the case for the U.S. Apollo program, the Soviet effort does not appear to be predicated on near-term economic benefits.

The last 5 years have witnessed a growing maturity and confidence in Soviet spaceflight planning and conduct. Present Soviet activities with Salyut are approaching the establishment of a permanent human presence in low-Earth orbit.[47] Whether or not continuous human occupancy is established soon, the Soviet Union can be expected at least to maintain and probably to expand human activities in space. The Salyut space station is anticipated to remain the central element for space operations involving people, although several new programs may augment the station's use and enhance the range of future Soviet options.

Three New Initiatives

Soviet planners appear to be looking at three new initiatives: modular space stations, heavy-lift expendable boosters, and reusable launch vehicles. President Brezhnev was apparently a strong supporter of space expenditures; President Andropov's views are not fully known.[48] Although appraisals of Soviet spending are difficult,[49] one estimate puts the overall cost of the Soyuz/Salyut program during the 1970's at nearly $40 billion (in 1980-adjusted dollars). That is approximately the cost of the entire U.S. Moon Landing program—from the first Mercury suborbital flight to the final Apollo 17 Moon landing and return.[50] Moreover, the cost to develop, launch, and maintain Salyut 6 during its nearly 5-year tour-of-duty probably exceeded $9 billion (in 1980-adjusted dollars).[51] As in the United States, the economic climate in the Soviet Union might well dictate the scope, scale, and timing of any new Soviet space initiative.

Modular Space Stations

A modular station could be composed of five to eight units, separately launched and assembled in orbit. These plans are well within current Soviet capabilities. Indeed, Soviet sources have identified Cosmos 929-class modules as prototypes:

> . . . of the kind that will be linked together to form a multi-purpose orbital station. One of the modules will be a fitted-out laboratory, others will perform purely technological duties. There will also be observatory modules and whole plants for manufacturing products in zero-g. Lounge modules will be living quarters for cosmonauts to take a rest after the heavy workload they will handle in space. . . . Each station can easily be modified by changing modules to fit changing needs of the mission . . .[52]

Within a constellation of such modules, Soviet cosmonauts could begin to live in orbit more comfortably and more productively. A modular space station could be the beginning of a usefully permanent human presence in space. Among other possibilities, the crew of a large, well-equipped station would no longer have to be limited to broadly trained cosmonauts. Technicians with particular specialties could be included in the station's complement. In any case, a large modular

[47]Rolf Engel, "Soyuz and Salyut: Stepping-stones to a Permanent Soviet Space Station?" *Interavia*, February 1982, pp. 173-177.

[48]According to one Western source, no major change in the Soviet determination to expand in space is to be expected. See: Theo Pirard, "Russia's Future in Space," *Space Press*, June 1983, pp. 16-17.

[49]See, for example: "Estimating Soviet Military Spending—An Arcane Art With Political Overtones," by Michael R. Gordon, *National Journal*, June 26, 1982, pp. 1140-1141. Gordon discusses the controversy surrounding U.S. estimates of Soviet military spending which are used to justify increased American military budget requests.

[50]Engel, op. cit., p. 175. These estimated costs for the Soviet program include expenditures for investment, infrastructure, and development.

[51]Saunders Kramer, "Salyut Mission," in Letters to the Editor, *AW&ST*, Oct. 27, 1980, p. 76.

[52]Dr. Feoktistov, quoted in DST-14005-022082.

station would allow human beings to achieve a more normal, leisured, and productive life in space than has hitherto been possible.

Heavy-Lift Expendable Boosters

Currently, Salyut operations are carried out using two types of launch vehicles. The "A" series booster, which provides over 400 tonnes of thrust at liftoff, is the workhorse of the Soviet launcher family.[53] Variants of this booster are used to loft Soyuz, Soyuz T, Progress, and other vehicles. This standard launch vehicle, minus its upper stage, was used to orbit Sputnik 1 into space in 1957—an indication of its reliability and longevity.[54] "D" series boosters, called "Protons," have launched Salyut space stations and Cosmos 929-class modules without cosmonauts onboard. The Proton's thrust at liftoff equals about 1,000 tonnes. There are also "C" and "F" series boosters which meet other requirements, but those of the "B" series have been phased out.

Under development, according to reports reaching the West, is a new booster in the "G" series capable of producing up to 5,000 tonnes of thrust at liftoff. Previous boosters in this series were apparently destroyed in three inaugural attempts (1969, 1971, and 1972): one exploded on the launch pad and two exploded in flight. Similar to the U.S. Saturn V, the redesigned G booster, possibly carrying cryogenic upper stages, is several years away from operational status, though test flights could occur between 1984 and 1986. A Pentagon analysis claims the booster will be capable of putting very heavy payloads into orbit (180 to 210 tonnes)—six to seven times the payload weight of the U.S. space Shuttle.[55]

Some believe the new "G" series booster will lead to the long-awaited Soviet attempt to put cosmonauts on the Moon. Others believe it will be used to orbit very large electromagnetic weapons. The new booster could also propel a 90-tonne station into orbit, to be occupied by a dozen or more crewmembers by the end of the decade. Such facilities might, in some respects, be more attractive than space stations built from smaller modules. With relatively small-sized modules, such as the Cosmos 929-class, for example, there may be as much as 30 percent redundancy of hardware for rendezvous, docking, propulsion, electrical power, structural support, and the like. In a larger station, the weight of this otherwise employed hardware could be used instead for additional instrumentation, living quarters, manufacturing facilities, and other productive equipment. All of these uses could be fulfilled by such a launcher. As an alternative to developing such a "G" series launcher, the Proton booster might be upgraded to carry cosmonauts. This choice would allow some modest improvements and avoid the risks inherent in developing a new launcher.

Reusable Vehicles

The Reusable Space Plane.—Speculation concerning a Soviet version of the U.S. Dyna-Soar has been fueled by two Cosmos flight tests, each apparently designed to evaluate the aerodynamic and reentry characteristics of a winged space plane, weighing about a tonne. These missions—Cosmos 1374 on June 3, 1982, and Cosmos 1445 on March 15, 1983—flew identical trajectories; each was sent into space for a 2-hour test from the Kapustin Yar launch site near Volgograd, orbited the Earth, and landed in the Indian Ocean. A seven-ship Soviet task force supported both retrieval operations. Photographs of the Soviet recovery of Cosmos 1445, released by the Royal Australian Air Force, indicate the craft is of a lifting-body/blended-wing design.[56] Some Western experts contend that the recovered vehicles are prototypes designed to provide reentry data for a larger 10- to 20-tonne version which would carry a crew. (By contrast, the U.S. space Shuttle weighs approximately 100 tonnes.) The Soviet tests have been likened to the U.S. Asset program of the early 1960's, which made use of several

[53] Appendix A describes this booster in more detail. See also Glushko, Valentin, Petrovich, "Development of Missile Construction and Cosmonautics in the U.S.S.R.," *Mashinostrayeniye* (Moscow: Machine Industry Publishing House, 1982), p. 66.

[54] James Oberg, "Beyond Sputnik's Booster," *Omni*, October 1982, pp. 22, 189.

[55] *Soviet Military Power* (Washington, D.C.: U.S. Department of Defense, 1981), pp. 79-80.

[56] See the following: Craig Covault, "Soviets Orbit Shuttle Vehicle," *AW&ST*, June 14, 1982, pp. 79-80; "Soviets Launch Winged Spacecraft," *AW&ST*, Mar. 21, 1983, p. 18; "Soviets Recover Spaceplane in Indian Ocean," *AW&ST*, Mar. 28, 1983, p. 15; and "Soviets Recover Spaceplane," *AW&ST*, Apr. 4, 1983, p. 16. See also: U.S. Department of Defense, *Soviet Military Power*, March 1983, pp. 66-68.

Credit © C. P. Vick, 1983

Projected Soviet Space Vehicles, the redesigned G booster, the heavy-lift shuttle, and the space plane, compared with earlier boosters, the unsuccessful G-1-e and the current D-1

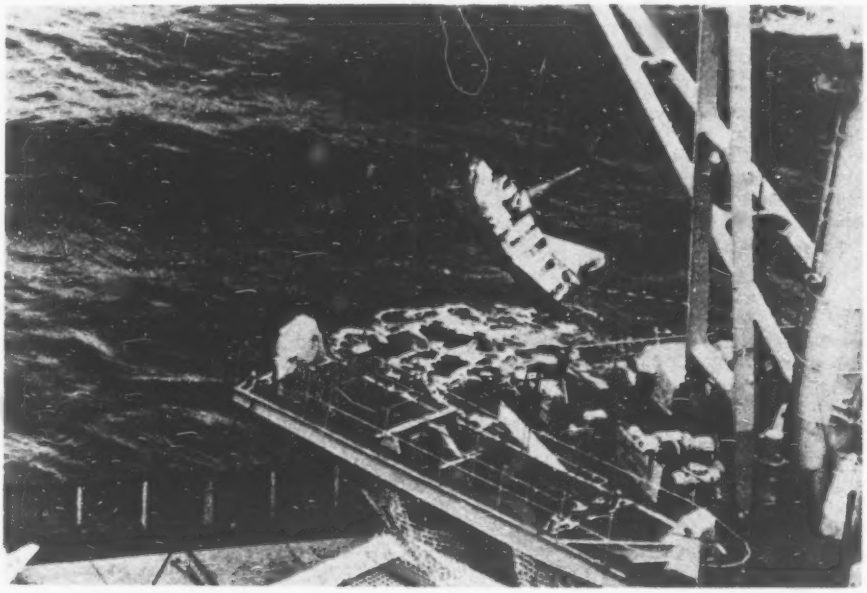

Photo credit: Australia Department of Defence

Recovery of Cosmos-1445 by the SSVRS 201 YAMAL is believed to be a quarter-scale testbed version of the Soviet space plane

gliders on suborbital flights into the Atlantic, to gather heating and structural load information on winged space vehicle designs.

Some Western observers believe this program may have begun as early as 1976. Drop tests of the Soviet space plane from aircraft, akin to those carried out in the U.S. space Shuttle program, have been reported.

The Soviet space plane is expected to be capable of ferrying three persons between the ground and the Salyut station or other platforms in low-Earth orbit. It should be able to provide a means of rapid evacuation from the station and sufficient cross-range to allow landing at any major airport. However, its design may make little, if any, cargo space available, thus affording no solution to the Soviets' inability to return heavy payloads from space stations to Earth. Although less versatile than the U.S. Shuttle, its greater simplicity might be well-adapted to quick launch and turnaround as well as rapid response to occasional reconnaissance requirements. Operation of the vehicle may begin within 2 to 3 years.

The Reusable Heavy-Lift Shuttle.—According to an assessment by the Department of Defense, the Soviet Union is apparently building a "heavy-lift" space shuttle similar in design to the U.S. Shuttle but capable of lofting twice as much payload into orbit. As detailed in a 1983 report on Soviet military power,[57] [58] the heavy shuttle, like the U.S. Shuttle, will be a delta-winged orbiter mounted on an external tank with strap-on

[57] *Soviet Military Power*, 2d ed. (Washington, D.C.: U.S. Department of Defense, March 1983), pp. 64-69.

[58] Craig Covault, "Soviets Building Heavy Shuttle," *AW&ST*, Mar. 14, 1983, pp. 255-259.

boosters. However, its ratio of payload weight to total vehicle weight is judged to be higher than that of the U.S. vehicle, and the specific impulse of its liquid-fuel strap-on boosters could be higher than the Shuttle's solid-fuel engines. In addition, the U.S. Shuttle carries 40,000 lbs of main engines and propulsion equipment on the Orbiter itself, whereas the Soviet shuttle would carry them on its main tank. This general configuration, whereby the Soviet shuttle would not have to recover its high-energy main engines, would result in a large payload bonus, though this advantage would have to be weighed against the cost of replacing the (unrecovered) engines. Overall, although its precise configuration and propellants are not known, the Soviet shuttle, with liquid strap-on boosters, could provide a payload capability of perhaps twice that of the 65,000 lbs of the U.S. Shuttle.[59]

Although the smaller space plane has been undergoing tests for several years, the heavy-lift shuttle design is relatively new and would require, perhaps, a decade of development and testing before it would be ready for regular use. Advanced versions of the vehicle could evolve into a two-stage, fully reusable system.[60] [61] At the Tyuratam spaceport near the Aral Sea, where Soviet cosmonauts are often launched, a large runway has been built and could be used to support operations for either type of reusable spacecraft.[62]

General Considerations

Although both types of Soviet reusable spacecraft may be realized in the relatively near future, Western experts disagree on the roles these vehicles might play with cosmonauts aboard. Some have suggested that the space plane could serve the Soviet military as a "space fighter."[63] Others think that the Soviets plan to use it as a replacement for Soyuz T vehicles. The heavy-lift shuttle, on the other hand, could well have an important role in boosting a new and larger generation of space-station modules into orbit.

The Soviets have bitterly criticized the U.S. space Shuttle as evidence of the "militarization of space" despite the official U.S. position that the craft is not a weapon. Soviet criticism may arise from a genuine fear of its use for military operations, or it may be a smoke screen to be maintained only until the Soviet Union can unveil a similar vehicle.[64] Soviet protests against U.S. military reconnaissance satellites, for instance, subsided once the U.S.S.R. had launched comparable spacecraft.

[59]See Picard, op. cit. It should be noted, however, that previous Soviet practice has been to rely on space structures that, relative to comparable U.S. structures, are heavy. If this practice is continued in the heavy-lift shuttle, and if this vehicle does indeed rely exclusively on liquid propellants, then a payload capacity double that of the U.S. Shuttle would imply a thrust at lift-off of some 3,000 to 4,000 tonnes.

[60]Craig Covault, "Soviets Developing Fly Back Launcher," *AW&ST*, Nov. 6, 1978, pp. 19-20.

[61]For further views on a Soviet space shuttle system, see: "A Soviet Space Shuttle?" by Kenneth Gatland, *Spaceflight*, September-October, 1978, pp. 325-326. Also, "The Soviet Space Shuttle Program," by Lt. Carl A. Forbrich, *Air Univ. Review*, May-June 1980, pp. 55-62, and "The Soviet Space Shuttle: Sifting Fact From Rumor," by James Oberg, reprinted in *Insight*, the newsletter of the National Space Institute, June-July 1980, pp. 4, 9.

[62]Pictures of the runaway have now appeared in *AW&ST*, Mar. 21, 1983, pp. 20-21.

[63]"Soviet Militarization of Space," *Air Force Magazine*, March 1982, p. 42.

[64]Soviet sensitivities as to the military usefulness of the U.S. Space Shuttle and its potential for sparking Soviet "technological inferiority" are evidenced in: *Soviet Elites—World View and Perceptions of the U.S.*, by G. Guroff and Steven Grant, Office of Research, International Communications Agency, R-18-81, Sept. 29, 1981, p. 17. Report observes:

> The U.S. space shuttle, in particular, seems to have left Soviets, including some at the highest levels, almost speechless. When they saw on television (private showings) what the U.S. had done, it was clear to many that their erstwhile "lead" in the manned space race had disappeared, and that their own program was years behind that of the U.S. Given the wide publicity of Soviet space efforts, many Soviets felt until then that the U.S. had all but abandoned space to the Soviet Union.
>
> Many believe that they are incapable of doing what the U.S. has done with the shuttle. This feeling translates for most Soviets into the further belief that if the U.S. wants to, it can change the military balance in its favor almost overnight—that it can pull some weapon/rabbit out of its technological hat at any moment and leave the Soviet Union far behind in the arms race.

Soviet concern regarding U.S. intentions to develop a space weapons capability could be amply fueled by such documents as: *High Frontier—A New National Strategy*, a Project of the Heritage Foundation, Washington, D.C. 1982, which calls for, among other elements, a military "high performance spaceplane" for inspecting or retrieval of "suspect" space objects.

American perceptions of the Soviet military presence in space is typified by: "Twenty-five Years After Sputnik—The New Soviet Arms Buildup in Space," *The New York Time Magazine*, Oct. 3, 1982, pp. 30-34, 89, 92-93, 98, 100.

Impact on Foreign Policy

The Soviet Union's space program is intended to demonstrate, inter alia, what can be achieved under its form of government. To this end, the Soviets have made political capital out of their guest cosmonaut program: a number of cosmonauts from Soviet-bloc countries—Czechoslovakia, Poland, East Germany, Bulgaria, Hungary, Vietnam, Cuba, Mongolia, and Romania[65]—were ferried to Salyut 6 for short-duration working visits. A French spationaut was transported to and from Salyut 7. Preparations are underway to include a crewmember from India in early 1984, and other countries may be invited to participate in future missions. How valuable is the guest program? At a minimum, it supports Soviet propaganda aims, and the scientific exchange, particularly with the French, may be of significant value. In any case, the Soviets clearly believe that the program is worth the relatively small investment required.

These international activities suggest the Soviets have decided to make their space program somewhat more open. Recently, they have also begun to announce some launch dates and to allow outsiders to observe payload processing, to view launches, and to access scientific data more quickly.

In contrast to the United States, the Soviet Union, in the view of some, is much more aggressive in deploying its space program as an important element in its foreign policy. Increasing openness may be the forerunner of greater cooperative efforts, particularly in the use of more instrumentation from Eastern European sources. The cooperative Soviet-French venture to probe Venus and Halley's Comet, for example, will incorporate more sophisticated technology than the Soviets have previously used, thus increasing its chance of success.[66]

Whereas the Apollo-Soyuz Test Project (ASTP) came to fruition as a product of detente, similar joint U.S.-Soviet ventures involving space stations are viewed by many as out of step with current political realities. Others suggest that such ventures are technically logical and diplomatically feasible.[67] There is also a possibility that cooperative space ventures could become polarized: the Soviet Union might increase its working relationships with Eastern European countries and, perhaps, France, while the United States works with Japan, Canada, and Western Europe.[68] Future Salyuts could incorporate "internationalized" modules dedicated to specific scientific research or commercial application.

The impact of an evolving Soviet space station program on U.S. space policy is unclear. Many observers agree that a U.S.S.R. pronouncement that a "permanent presence in space" had been achieved would do little to reshape U.S. civilian space objectives. Even bolder announcements of Soviet intentions to send human beings to the Moon or to traverse interplanetary distances to establish a human presence on Mars, might have little influence on U.S. pursuits. Creation of a significant and obvious military installation in orbit, however, might well dictate an American response in kind.

In the end, a U.S. response to any new Soviet space project would be heavily influenced by public opinion and the circumstances of that moment. It is impossible to predict with much assurance just what Soviet activities might trigger an important American reaction.

[65] The last six are in Cyrillic alphabetical order. See J. Oberg, *Red Star in Orbit*.

[66] "French, Soviets Weigh Venus Mission," *AW&ST*, Nov. 22, 1982, pp. 79-80.

[67] See, for example, "Hitch Up With a Red Star," James Oberg, *OMNI*, March 1982, p. 20.

[68] "NASA Mulls International Effort on Space Station," *AW&ST* Mar. 1, 1982, pp. 20-21.

Conclusion

In any characterization of the future of the Soviet space program, caution is the rule. Western forecasters during the past 5 years expected a more dynamic effort than the Soviets actually put forth. Still, the Soviets have shown considerable perseverance, and their predictions about even bigger space stations—capable of housing "large collectives" rather than small crews—should be taken seriously. Modularized space facilities—carrying equipment for astronomical, physical, and chemical experiments, and for technology development purposes, adapted for multidisciplinary programs for both civilian and military purposes—can be expected.[69] It is possible that useful and marketable products and services could be provided. Such stations, situated in various orbits, would be a straightforward extension of demonstrated Soviet capabilities. Eventually, these same facilities could involve international teams.

With a sufficient commitment of resources, the Soviets may be able to maintain a continued human presence in space through the use of heavy-lift launchers and/or expanded use of currently available boosters. A shuttle-type vehicle would permit routine access to platforms in near-Earth orbit. A large Salyut complex could serve as a space transportation node or base camp.

As recently as late November 1983, the Soviet newspaper *Pravda* asserted that the main thrust of Soviet cosmonautics is "the creation of [sophisticated] orbital manned complexes, which can be improved during lengthy use and be reconstructed depending on the nature of the tasks being tackled."[70] The next step in the Soviet space program will aparently be "the transition from long-term orbital stations regularly visited by replacement crews to a multi-team, permanently manned orbital complex."[71]

From a permanent foothold in near-Earth orbit, the next step might be an extension to geostationary orbit. Soviet scientists have argued that a series of orbital stations might one day stretch for hundreds of miles in a given orbit.[72]

Salyut operations are one step in the Soviet drive toward mastery of space. It is quite conceivable that, by the end of the century, they cound put cosmonauts on the Moon.[73]

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[69]Comments of Anatoly Skripko, Science and Technology Attache to the Soviet Embassy in Washington, D.C., at a luncheon of the American Astronautical Society, Feb. 12, 1982. See also "Soviets Initiating Program on Modular Space Station," by Craig Covault, *AW&ST*, July 20, 1981, p. 22, and "Soviets Move Toward Space Operations Center," James Oberg, *Aeronautics and Astronautics*, May 1982.

[70]Quotation from *Pravda*, Nov. 25, 1983, appearing in *Aerospace Daily*, Dec. 1, 1983, p. 155.

[71]*Pravda*, Nov. 28, 1983, quoted in *Aerospace Daily*, Dec. 1, 1983, p. 155. The article continued as follows: "*Pravda* said the size of such a complex will be impressive even by the standards of construction on Earth. For instance, the parabolic antenna alone should have an effective aperture . . . [o]n the order of 300-350 meters. In addition, it must be geared to a long period of operation—15-20 years as a minimum.

"*Pravda* said that '[t]oday, this complex is conceived as a unified system of large-scale installations in orbit at an altitude of 200-400 kilometers, linked to Earth by freight and passenger transport spacecraft. The complex will include specialized scientific research laboratories, comfortable housing modules, powerful energy installations, a refueling station, repair workshops, and even construction sites for producing and installing standardized construction components. The real potential of orbital flight for the *ad hoc* solution of urgent national economic tasks will also be expanded many times over.'"

[72]Yuri Zaitsev, "Orbital Stations—The Present and Future," *Moscow News*, #45 (2825), Nov. 19-26, 1978, p. 11.

[73]"The Soviets think that in about 20 years a journey to Mars may be possible. By this time, spaceships may incorporate centrifuges that simulate the conditions of living under gravity." Smolders, op. cit., p. 944.

Postscript

According to accounts published in U.S. newspapers on October 12, 1983,[74] the Soviets announced a nearly disastrous setback when an A-2 rocket, bearing a Soyuz T and two cosmonauts, exploded on a launch pad at the Tyuratam cosmodrome. Apparently, just prior to scheduled liftoff, a fire was detected at the base of the launch vehicle, and the launch escape system was triggered, either by automatic failure detection circuitry, the blockhouse crew, or the cosmonauts themselves. The launch escape tower rocket ejected the Soyuz orbital module and the descent module carrying the cosmonauts moments before the booster exploded beneath them. Subsequently, the descent module was separated from the orbital module and parachuted to Earth. The escape rocket subjected the cosmonauts to a high velocity, high G, escape trajectory, and the landing impact velocity was substantially higher than the normal 3.3 feet per second. Both may have sustained some injuries. This two-man crew was to have made a week-long resupply visit to the two cosmonauts who have been aboard Salyut 7 since June 28, 1983.[75]

This accident did not seem to have placed the crew aboard the Salyut in any great danger because they were resupplied by Progress 17 in mid-August and Progress 18 in October and because they were resupplied by Progress 17 in mid-August and Progress 18 in October and because their Soyuz T-9 was still capable of returning them to Earth. In addition, the Soviets have at least three other (undamaged) launch pads at Tyuratam, and almost certainly have another Soyuz T and an A-2 booster which could have been integrated and readied for launch on short notice. The degraded condition of Salyut 7, however, adds additional uncertainty for future missions. The Soviets have announced that the most recent crew of cosmonauts returned to Earth on November 23, 1983, after a mission of 150 days.

Coincidentally, NASA has had to postpone the first flight of Spacelab aboard the Shuttle because "a liner that protects the lowest part of one of the [reusable] solid-rocket engines from heat" was almost burned through during the previous Shuttle flight.[76] If the flame had burned through part of the engine in flight, the Shuttle would have become aerodynamically unstable some 2 minutes after launch; the result could have been a catastrophe.

The U.S.S.R. accident and the U.S. near-accident indisputably show that space operations are still hazardous, even with systems that have been flight-proved time after time.

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[74] *Washington Post*, Oct. 12, 1983, p. A-9; *New York Times*, Oct. 12, 1983, p. A-7.

[75] For a thorough discussion both of the accident and of the failure aboard Salyut 7, see the article "Explosion, Leak Cripple Salyut 7 Effort," *AW&ST*, Oct. 10, 1983, pp. 23-26.

[76] *The Washington Post*, Oct. 13, 1983, p. A-15.

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Appendix A:

The Soviet Salyut Space Program: Space Station, Spacecraft, Support and Training Facilities

Material provided to OTA by Dr. Balayan, Vice Chairman of the Intercosmos Council of the U.S.S.R. Academy of Sciences.

The Salyut Orbital Scientific Station

The creation of the Salyut orbital stations is an important stage in the development of Soviet cosmonautics, intended to increase the length of both manned and unmanned flights.

The total mass of the orbiting scientific complex, including two transport ships, is 32,500 kilograms (kg); the mass of the space station in orbit is 18,900 kg, the mass of the transport ship in orbit is 6,800 kg.* The dimensions are as follows: 1) total length docked with two transport ships 29 meters (m), 2) station length 15 m, 3) maximum station diameter 4.15 m, and 4) maximum transverse station dimension with solar panels open 17 m.

More than 20 portholes are provided for the conduct of scientific experiments, visual observation, and still and motion picture photography from the compartments of the station.

Hatches in the docking units are used to allow the crew to move between the transport ship and the station. After docking, the crew can work and rest both in the compartments of the station and in the transport ships, moving through these hatches.

Terrestrial conditions are maintained in the sections of the station in orbit—the same gas composition, atmospheric temperature and pressure, providing the necessary conditions for the cosmonauts' activities.

Composition and Arrangement of Orbital Station

The station consists of five compartments: transit, operations, scientific apparatus, intermediate, and equipment compartments.

During powered flight the external elements of the transit section and parts of the small-diameter operations section are protected from aerodynamic forces by fairings which are later jettisoned.

The scientific equipment installed in the scientific apparatus section is protected during powered flight by a scientific apparatus cover which is also jettisoned after orbital insertion.

The transit section is bounded by conical and cylindrical (2 m diameter) sealed envelopes.

The passive portion of the docking unit—the "cone"—is installed at the conical end of the section (the active "rod" docking unit is installed on the spacecraft), while the cylindrical portion of the section adjoins the operations section of the orbital unit.

There is a hatch in the conical envelope of the transit section to allow servicing of the station on Earth and to allow the crew to exit into space. The outer surface of the transit section carries:

- antenna of the approach and docking unit;
- optical lamps for orientation during manual docking of spacecraft;
- external television cameras;
- panels with temperature regulation units;
- gas storage cylinders of the life-support system containing air;
- ionic and solar sensors of the station's orientation system;
- handles and restrainers for cosmonauts in spacesuits performing space walks; and
- panels for the study of micrometeorites, contamination of optical surfaces, and properties of rubber and biologic polymers.

The outside of the transit section and the apparatus installed on it are covered with a vacuum-shield thermal insulation to maintain the required temperature conditions.

Within the transit section, which is used as a lock, are spacesuits, panels, equipment and attachment devices to support space walks.

There are seven portholes in the transit section. Some carry instruments for astro-orientation of the station. These instruments, together with the corresponding control panels and knobs which control the orientation of the station, form two control posts (post Nos. 5 and 6).

*These masses appear to be related to Salyut 6 and Soyuz craft.

The transit section connects to the operations section of the station through a sealed airtight hatch. The operations sections consists of two cylindrical shells (2.9 m diameter and 3.5 m length, and 4.1 m diameter and 2.7 m length) connected by a conical section (1.2 m in length).

The cylindrical shells have spherical ends. The posterior end has a hatch which connects the operations sections with the intermediate chamber.

In the operations section, equipment is arranged along the section forming a common passageway beside the equipment, with instruments and equipment located to the left and right. The instruments and equipment are installed on standard racks which form the frame of the interior.

Most of the monitoring and control systems and scientific apparatus of the station are in the operations section. The apparatus with which the station crew works directly is grouped by functional purpose in five control posts (there are two additional control posts in the transit section, as was mentioned earlier).

Post No. 1 is the central control post of the station, where control of the main station systems is concentrated. It is located in the lower portion of the operations section (in the small diameter area). This post has two working locations equipped with chairs (for restraint), communications equipment, control panels, a lever to control the angular position of the station in space, optical sites of the orientation system, and portholes with no equipment.

To the left and right of the control panel are the regenerator cartridges of the station's gas-mixture support system, as well as the refrigeration and drying units of the temperature control system. Near the forward end of the operations section beyond control panel No. 1 are the gyroscopic instruments of the orientation and motion control system, mounted on a rigid frame.

Post No. 2 (the astropost) is also in the lower, small diameter portion of the operations section, closer to its conical portion. This post is used for astro-orientation and astro-navigation of the station. The post is equipped with communications equipment, an orientation control panel, and astro-instruments (installed on two portholes).

Between post Nos. 1 and 2 in the small diameter end of the operations section is the area where the crew eat and rest. In this area is a table with special devices for heating food. A drinking water container is attached to the table. Along the right side in this area is the system which regenerates water from atmospheric moisture condensate. The cosmonauts obtain hot and cold water from this system. Behind the interior panels on the left side is the onboard computer apparatus. The cosmonauts can perform minor preventive repair of equipment on the table in this area, for which they have a special onboard toolkit available.

Post No. 3 is intended to control the apparatus located in the scientific equipment section. This post is located in the large diameter portion of the operations section in its lower part near the rear end. Control panels, communications equipment, and retainers are installed here.

The instrument zone contains the onboard radio system, radio telemetry system, and power supply system control apparatus. Near the aft end of the operations section on the left and right sides are the crew's bunks, and in the instrument area there are food storage containers.

In the upper portion of the operations section (near the aft end) are two locks for jettisoning the crew's wastes into space. Wastes are collected in special containers and, after they are ejected from the lock chamber, burn up in the atmosphere.

On the aft end of the operations section is the head. It is separated from the remaining portion of the operations section and has forced ventilation. Beside it is a vacuum cleaner, dust filters, storage for water, linens, and other life-support system consumables.

In the forward, larger-diameter portion of the operations section is a system allowing the crew to shower periodically.

Post No. 4 is in the lower central portion of the operations section near the conical shell. Here is the equipment used for most of the medical experiments, still and motion picture cameras, and the scientific apparatus control panel. This post has cosmonaut restrainers and communications equipment.

Near post No. 4 is the system used to prevent ill effects of weightlessness on the cosmonauts. It includes:

- a treadmill and other devices for physical exercise;
- a bicycle ergometer;
- a pneumatic vacuum suit to create low pressure on the lower portion of the body; and
- a muscle tissue stimulation apparatus.

One of the two portholes at post No. 4 carries an MKF-6M multiple-zone survey camera manufactured by Karl Zeis Jena of East Germany with electronics and control panel.

On the left and right sides near post No. 4 are the refrigeration and drying units of the temperature control system, the onboard radio apparatus, electronic units of the orientation system, and station movement control system.

Post No. 7 works in cooperation with the scientific equipment control post and water regeneration system control. This post is located in the central portion of the small diameter operations section.

Control panels are mounted on the interior to the

left and right; the cosmonaut who works here is restrained in a reinforced seat.

All control panels and cosmonaut working locations are equipped with internal loudspeaker communications devices and daylight lamps. Other lamps are used to create general illumination in the living space. During still and motion picture photography and television reports, the cosmonauts turn on additional lights to provide the necessary illumination for the cameras.

Most of the outer surface of the small diameter operations section is covered with the temperature control system's radiator. On the left and right sides and in the upper portions of the section are three solar battery panels. Special drives rotate the panels toward the Sun at all times. In the forward portion of the operations section are the solar battery orientation system sensors, which determine the position of the Sun in the forward hemisphere as the station moves. Outside the lower portion of the small diameter operations section are the automatic station orientation instruments (an infrared vertical, solar sensor, television orientation device, etc.). Outside the conical portion of the operations section is a special repeating action cover with electric drive to maintain the temperature of the porthole through which the MKF-6M camera operates.

On the outside of the large diameter operations section are the onboard radio system and telemetry system antennas.

To maintain the proper temperature the body of the operations section is covered on the outside with mats of vacuum shield heat insulation, while the large diameter portion of the section is also covered with a fiberglas cover for protection from aerodynamic heating during powered flight. On the sides of the station are panels with sensors to study the flux of micrometeorites.

The unsealed cylindrical equipment section (4.15 m diameter, 2.2 m length) contains:

- the combined motor installation, including correcting motors and a system of low thrust motors which creates controlled torque to orient the station in space; and
- tanks of fuel.

On the outer surface of the equipment section are:

- the approach and docking radio antennas;
- optical lamps for orientation during manual docking of spacecraft with the station;
- the solar battery orientation system sensors, which determine the position of the Sun in the aft hemisphere (with respect to station flight);
- the onboard radio system antennas, and
- a television camera to monitor docking of transport spacecraft.

The equipment section is thermostatted in flight and has external heat insulation similar to the insulation of the operations section. The equipment section is connected to the end of the operations section; its aft end is connected to the booster rocket.

The scientific apparatus section is in the large diameter cylindrical portion of the operations section. It is a combination of conical and cylindrical shells (maximum 2.2 m diameter). The end of the section is oriented toward outer space and is equipped with a cover.

The intermediate chamber of the station is a sealed section consisting of cylindrical and conical shells 2 m in diameter with a total length 1.3 m. The second docking unit of the orbital station is mounted through the conical section on the intermediate chamber.

The intermediate chamber is used to carry equipment delivered by the transport spacecraft. An air line is laid through it to supply air from the operations section to the transport ship to create a common atmosphere. The intermediate section has two portholes used for visual observation, still and motion picture photography and television reporting.

Systems of the Orbital Station, Their Purpose, and Main Operating Modes

1. Onboard Equipment Control System (SUBK).—The SUBK controls the onboard systems:

- automatically (by a programed timer);
- on radioed command from the Earth; and
- on command of the cosmonauts at the control panels.

The SUBK switches the electric power supply system and protects the power supplies from short circuits, controls the pyrotechnic cartridges which open and deploy external elements of the structure, etc., and outputs information on the results of operations to the cosmonauts' panels and to Earth.

2. Orientation and Motion Control System (SOUD).—The SOUD is intended to orient and control the motion of the space station in automatic and manual modes.

The SOUD includes:

- a sensor apparatus (sensing elements):
  - —solar sensor;
  - —infrared vertical device (IKV);
  - —gyroscopic angular motion sensors;
  - —an ionic sensor;
  - —free three-way gyroscope; and
  - —velocity increment integrator.
- manual instruments:
  - —a wide-angle orienting site;
  - —optical orientors;
  - —an electronic-optical converter; and
  - —an astro-orientor.

- the "Kaskad" apparatus to maintain long-term orbital and inertial orientation;
- the approach electronic apparatus;
- lamps and targets for manual approach and docking; and
- automatic equipment and electronic units.

3. Combined Motor Installation (ODU).—The ODU is intended to create controlled torque around the center of mass of the station by means of low-thrust motors, and to generate power to move the station by means of the high-thrust motors.

The combined motor installation includes:

- correcting motors (two); and
- orientation motors.

The motors are supplied with fuel from two groups of collectors, each of which supplies the motors through three station control panels—pitch, yaw and roll.

4. Command Radio Link.—The system is intended to transmit control commands and settings from the Earth to orbit, trajectory measurements, two-way telephone communications between Earth and the station, and television and telemetry information from the station to Earth.

The system includes receivers, transmitters, antenna-feeder device, a programed timer (PVU), decoder, and other electronics and automation equipment.

5. Television Communications System.—The television system is used to transmit color and monochrome images from the onboard television cameras to Earth and to the onboard television screen (VKU).

The system includes:

- external stationary television cameras (monochrome images);
- the reporting television camera (color);
- the reserve reporting camera (monochrome);
- video monitors (VKU);
- the antenna-feeder devices;
- special lamps; and
- automation and electronic equipment.

6. Telephone Communications System.—The "Zarya" radiotelephone communications system is intended to provide two-way Earth-station and station-spacecraft communications in the ultra-short wave (USW) and short wave (SW) bands. The system includes USW receivers and transmitters, SW receivers and transmitters, and antenna-feeder devices.

To provide loudspeaker communications within the sealed station sections, there are loudspeakers, microphones, and amplifiers at the control posts and working locations.

The transmission of text (alphanumeric) information from Earth to the station utilizes an apparatus with a printer.

7. Radiotelemetry Communications system (RTS).—The radiotelemetry system is designed to collect information and transmit it from the spacecraft to Earth. The station carries two RTS systems; one system is used for service information, the other for information from the scientific and experimental apparatus.

Independent magnetic recorders (MIR) with magnetic tape cassettes are used to record scientific measurements with high sampling frequency. The magnetic tapes are returned to Earth on transport spacecraft.

8. Orbital Control Radio System, Which Performs Trajectory Measurements.

9. Power Supply System.—The power supply system (SEP) provides electric power for all onboard systems of the station, and also charges the buffer batteries (BB) and supplies power to transport spacecraft docked to the orbital unit.

The system includes:

- solar batteries (SB); three solar battery panels are installed on three planes of the station;
- the main buffer battery (BB);
- the reserve buffer battery; and
- the power supply test unit (BKIP).

The SB panels are oriented toward the Sun by means of the solar battery orientation system (SOSB). When a minimal voltage is reached, all consumers are automatically disconnected except for the duty systems, and a switch is made to the reserve BBO. After spacecraft dock, the orbital unit SEP charges the BB and supplies the transport spacecraft as long as they remain docked.

10. Life-support system (SOZh).—The SOZh is intended to provide conditions which will support the life of the crew; proper pressure and gas composition of the atmosphere, food and water, sanitary-hygienic conditions, and space-walk support.

The gas composition support system (SOGS) is intended to liberate oxygen (O_2) and absorb carbon dioxide (CO_2) and other impurities.

The system includes:

- chemical O_2 regenerators;
- chemical CO_2 absorbers;
- gas analyzers;
- harmful impurity filters (FVPs);
- dust filters (PFs); and
- gas stored in cylinders.

Additional regenerators, absorbers, FVPs, and gas are delivered by transport and cargo ships to replenish the supplies and allow continued operations of the system.

The system can maintain the parameters of the atmosphere within assigned limits (CO_2 = 0.9 mm mer-

cury (Hg) O_2 = 160-280 mmHg, total gas pressure 760-960 mmHg) by manual connection and disconnection of regenerators and absorbers according to the readings of the gas analyzers.

The crew is supplied with water by regeneration of water from atmospheric moisture condensate and by reserves of stored water.

The water is stored in special containers.

Food is stored onboard the station as daily pacs in boxes. The food supply is supplemented by delivering it on transport and cargo spacecraft.

Sanitary-hygienic conditions are maintained onboard the spacecraft by means of a sanitary installation (ASU) [head—Tr.], shower, sets of linen, personal hygiene washcloths, and two lock chambers (ShK) with containers for waste ejection. Liquid wastes are collected in the sanitary device and ejected through the locks. Solid wastes (ASU, food, etc.) are collected in packets, then placed in special rigid containers designed for ejection through the locks.

Two spacesuits are used to allow two cosmonauts to perform space walks simultaneously. The transit section is used as a lock for this purpose.

11. Medical Monitoring and Prophylaxis Equipment.—This equipment is designed to allow regular medical monitoring of the cosmonauts' health and prevent harmful effects of spaceflight factors.

The system includes medical testing apparatus, an "Aelita" combined medical examination apparatus, a treadmill, bicycle ergometer, pneumatic vacuum suit, units for testing and indicating parameters of the crew's condition upon orbital insertion, and a pharmacy.

These devices are used for:

- regular medical testing, the information from which is transmitted to Earth through the telemetry channels;
- periodic medical examination with the "Aelita" apparatus, the data from which are recorded onboard the spacecraft and transmitted to Earth; and
- regular crew training (with a treadmill, bicycle ergometer, and pneumatic vacuum suit).

12. Temperature Regulation System (STR).—The STR is intended to support the proper temperature of structures, units, and apparatus of the orbital station and docked transport spacecraft, and to create comfortable temperature conditions within the habitation sections.

13. Docking and Internal Transfer System (SSVP).—The SSVP is intended to perform mechanical, electrical, and hydraulic docking of the orbital station with transport and cargo spacecraft, and to support internal transfer of cosmonauts from spacecraft into the station without passage through open space.

The docking unit is based on the rod (active portion) and cone (passive portion) principle.

The Soyuz T Transport Spacecraft

The Soyuz T spacecraft is an improved manned transport spacecraft for the delivery of the crew to Salyut orbital stations and return of the crew to Earth, as well as transportation of cargo.

The experience gained in the development of flights of Soviet spacecraft and stations was used extensively in designing the Soyuz T spacecraft.

The Soyuz T spacecraft is placed in orbit by a Soyuz booster rocket, which determined the size and mass of the new spacecraft. The well-proved Soyuz spacecraft, including the descent module, orbital (habitation) section, and instrument-equipment section, was used as the basis for arrangement of the new spacecraft.

However, the Soyuz T spacecraft differs in a number of details from the earlier craft, has improved characteristics and, particularly, increased effectiveness as a transportation vehicle for orbital space stations, plus improved reliability and crew safety.

The spacecraft is designed to carry up to three crew members in space suits. In addition to the special onboard systems, the spacesuits protect the crew in case of a loss of seal in the living spaces. If necessary, depending on the mission of each specific flight, the spacecraft crew may be reduced in number with no changes in spacecraft design. The free spaces are then used to carry special cargo containers, allowing, in combination with Progress spacecraft, the problem of delivering cargo to the station and returning cargo from the station to be solved.

Most of the onboard systems of the spacecraft were designed anew or modernized using systems design principles, new elements, and new production and testing technologies.

A new motion control system has been developed for the spacecraft, using an onboard digital computer. The system calculates motion parameters and automatically controls the spacecraft in the optimal mode with minimum fuel consumption, performs self-testing, and automatically switches if necessary to reserve programs and hardware, while outputting information to the crew via the onboard display.

The decisions implemented in the system assure higher accuracy, reliability, and flexibility of spacecraft control in both orbital flight and descent.

The crew can control the spacecraft manually not only in orbit but also during descent in the atmosphere.

The approach and correcting motor and docking and orientation micromotors operate with the same fuel components and have a common fuel storage and supply system, allowing more effective utilization of onboard fuel reserves. During flight the consumption of fuel is monitored by a special measurement system.

In order to improve reliability, the landing equipment system has been modernized, and the emergency crew rescue system, used as the spacecraft is placed in orbit, has been improved.

The radio systems of the spacecraft—such as the command-program radio link and radiometry and television systems—have been improved, and solar batteries have been included in the power supply system.

The design of the spacecraft provides for duplication of important mechanisms, sealing devices, separator units, etc.

The total volume of the living spaces aboard the Soyuz T is about 10 m³.

The Progress Automatic Transport Spacecraft

The automatic transport spacecraft is intended for delivery of the following items to the Salyut piloted orbital station:

- scientific apparatus, photographic materials, crew life-support supplies, instruments, and units in need of replacement; and
- fuel components to recharge the combined motor installation of the orbital station.

In addition, it provides for the removal of wastes and units which have completed their operating life from the space station.

The automatic cargo transport spacecraft has a launch mass of 7 tonnes and consists of three main structural units:

- the cargo section (GO) with docking unit;
- the fuel component section (OKD); and
- the instrument and equipment section (PAO), consisting of the transit, instrument, and equipment sections.

The docking unit of the spacecraft is based on the docking unit of the Soyuz manned spacecraft and is designed for mechanical docking of the spacecraft with the station, to assure an airtight seal, and also to connect electrical lines and automatically connect and seal the main fuel supply lines. The crew passes through the docking unit into the cargo section of the spacecraft.

The cargo section of the spacecraft is intended to carry instruments, scientific apparatus, photographic materials, food, water, and life-support system equipment, including regeneration installations, all mounted on special frames and in containers. Throughout the flight, with the docking unit hatch sealed, conditions are maintained in the cargo section as required to preserve all of the instruments and food products being delivered to the space station. The volume of the cargo section is 6.6 m³. The cargo section has an ordinary air atmosphere (760 mmHg). The temperature in the section is maintained between +3° and +30° C.

The cargo section is connected to the refueling component section. On the outer surface of the section are three antennas of the electronic approach system, two external television cameras (one aimed forward, the other toward the Earth), 103 light indices (used by the crew to monitor correct placement of the spacecraft during automatic approach and docking). Outside the section are the main lines which feed fuel components from the refueling section to the connections on the docking unit. The cargo section of the spacecraft can carry up to 1,300 kg of cargo to the orbital station.

The refueling component section structurally consists of two truncated conical shells. The section connects at one end to the cargo section, at the other end to the transit section and instrument and equipment section. At the outside of the section are two light indices which supplement the light index on the cargo section. This section is intended to carry tanks of fuel components for delivery to the orbital station, gas cylinders, and the equipment of the refueling system. The gas in the cylinders (nitrogen or air) is used to drive the fuel components during the refueling and also to fill the habitation compartments of the station if necessary.

The refueling system includes a system which tests the seal of the fuel lines, a blowing system, and sensors to monitor the temperature and pressure of the components and gas in the process of storage and refueling. During refueling, up to 1 tonne of fuel components can be transferred to the tanks of the combined motor installation of the station.

The refueling system is controlled by the crew of the orbital station, with radio signals from Earth controlling the cargo spacecraft end.

The instrument and equipment section is designed to carry all of the main service systems of the spacecraft supporting independent flight, approach and docking, flight as a part of the orbital station, and undocking.

The transit section of the instrument-equipment section is a framework which carries the fuel tanks, spherical containers, and fittings of the approach and orientation system motors. Outside the section are 10 approach and orientation motors of the system and the command radio link antenna.

The instrument and equipment sections are similar to the instrument and equipment sections of the Soyuz transport spacecraft in their design, purpose and apparatus, and equipment carried.

A Soyuz booster rocket is used to insert the transport cargo spacecraft into orbit.

After the cargo spacecraft separates from the booster rocket, structural elements carrying the antennas of

the electronic approach system and radiotelemetry system, as well as the panel carrying the light indices, are deployed from the spacecraft.

Basic Information on the Soyuz Booster Rocket

The Soyuz booster rocket has three stages.

Stage I consists of four lateral units, each of which is 19 m long, 3 m in diameter; its motor has four chambers, two of which are steering chambers, developing a total thrust in a vacuum of 102 tonnes.

Stage II is the central unit, about 28 m in length, maximum 2.95 m in diameter, its motor has four chambers, all of which are steering chambers, developing a total thrust in a vacuum of 96 tonnes.

Stage III is a unit with a length of 8 m and a diameter of 2.6 m; its motor has four chambers (with steering nozzles), developing 30 tonnes of thrust in vacuum. The launch mass of the booster rocket with a Soyuz T spacecraft aboard is over 300 tonnes.

When the booster rocket is launched, the motors of the first and second stages are ignited simultaneously. The second stage continues to operate after the four lateral units [of the first stage] are jettisoned. The third stage is ignited after the second stage motor has completed operation. The booster rocket uses kerosene-oxygen fuel in all stages. The total length of the booster rocket with a Soyuz T spacecraft is 49 m. The maximum diameter at the stabilizers is 10.3 m.

Controlling the Flight of the Salyut Orbital Scientific Station

Organization of Flight Control

Flight control of the Salyut orbital scientific station, transport and cargo spacecraft is provided by:

- the flight control center near Moscow;
- a network of tracking stations;
- a system of modeling devices including a mathematical model of the station and a physical model of the spacecraft; and
- a communications system with Earth and satellite-information transmission channels.

Flight Control Center

The flight control center performs the following tasks:

- operational administration and coordination of the operation of the entire system;
- collection, processing, and display of telemetry, trajectory, and television information arriving from the station and from transport and cargo spacecraft; and
- interaction with the launch and search and rescue systems, trainers and modeling equipment, and various organizations participating in flight support.

The flight leader and flight control personnel are located at the center. The flight control center is equipped with a computer system; devices for collection, processing, and display of information; internal communications and television; remote-command output; communications with the crew; and transmission of telegraph messages to the Salyut station. The control center is in communications with the Moscow television technical center at Ostankino.

The flight control center has been significantly improved. It now has a second control room to control the flight of the transport and cargo spacecraft and a modernized computer system which now allows the problem of controlling several spacecraft simultaneously to be solved. At the same time the number of communications channels between the center and tracking stations has been increased to support simultaneous transmission of telephone, telemetry, and television information to the center from three spacecraft over surface channels and through Molniya communications satellites.

The modernized computer system of the center and the improved communications system allow transmission, processing, and display of information from all telemetry sensors of the Salyut station and from Soyuz spacecraft simultaneously for the control personnel.

The flight control personnel operating with the Salyut and Soyuz spacecraft systems are a carefully selected trained team consisting of specialists of various profiles. They include specialists on the flight program and flight control organization specialists, onboard systems developers, designers of the station and transport spacecraft, scientists, ballisticians, physicians, communications specialists, as well as specialists on the control and maintenance of the tracking stations, flight control central hardware, communications system hardware, plus representatives of scientific organizations of our country and other socialist countries.

Most of the control personnel are located at the flight control center—this is the chief operational flight control group. Some of the personnel are located at tracking stations and on ships of the U.S.S.R. Academy of Sciences, the Priroda state scientific research and production center, and the center for medical and biological research. The total number of personnel is about 100. Successful performance of the flight mission and completion of scientific research and crew safety depend on precise operations by every man.

The organizational structure of the flight control center personnel was developed by specialists with experience in the organization of manned spacecraft and station flight control, is recorded in special organizational documentation, and has been repeatedly tested in training exercises and in controlling the flights of previous stations and manned spacecraft.

The flight leader heads the control personnel.

Flight control is performed from two rooms: the main station flight control room and the transport and cargo spacecraft control room.

The personnel in the rooms work under the control of shift flight leaders.

Each room contains: the shift flight leader; specialists responsible for the main onboard systems; persons responsible for the operation of tracking stations; persons responsible for planning the flight program and for complete analysis of the operation of onboard systems; a cosmonaut operator in communication with the crew; representatives of the organizations which develop the station and spacecraft; a ballistics expert; a physician responsible for medical monitoring of the crew; the shift center leader; and specialists responsible for the main system at the center (communications, computer system, display systems, etc.).

All specialists work at positions with individual display and communications equipment.

The personnel work in four shifts. Shift changes occur during flight with no delay in flight operations.

Since the flight control center, tracking stations, and communications equipment are all the same for the station and the transport spacecraft, priority had to be assigned for their use. During orbital insertion, approach, and docking of the transport spacecraft with the station, the transport spacecraft control room has priority for use of equipment.

After docking and movement of the crew into the station, priority is transferred to the main control room. Priority transfer occurs at the moment the transfer hatches between the spacecraft and station are opened.

Organization of Work in Control Room

Control of the station or transport spacecraft is transferred to the control center from the launch complex immediately after separation of the last booster rocket stage.

Up to this point the personnel in the control rooms monitor the operation of onboard systems by telemetry, observe the crew by television, and listen to the conversations between the crew and the launch team.

A central screen shows the course of the booster rocket's flight over the entire insertion trajectory. After separation of the spacecraft from the booster the personnel in the control room monitor the opening of the antennas by telemetry, make contact with the crew, and begin testing onboard systems.

Work in the room is organized as follows: When the spacecraft enters the zone of visibility of ground tracking stations (the movement of the spacecraft is displayed on the central screen in the main hall) commands are transmitted to the spacecraft in accordance with the flight program. The personnel in the room monitor the transmission of commands and their reception by the spacecraft. The necessary onboard systems are switched on by commands from Earth or by the crew. The tracking stations begin to receive and transmit to the control center the telemetry, trajectory information, and television images received from the spacecraft. As the telemetry and trajectory data are received they are automatically processed by the control center's computers and transmitted to the display devices in the control room.

Telemetry information is analyzed in detail by systems specialists who generate conclusions concerning the status and operation of each onboard system for the responsible personnel.

Those responsible for individual systems are in communications with the support personnel outside the control center and can, if necessary, consult with them or obtain additional information on the operation of the systems.

In case of abnormal operation of spacecraft systems, the specialist responsible for overall analysis determines the effect of any system failures on the operation of individual systems, prepares suggestions for elimination of defects and correction of onboard system-operating modes, and then reports these suggestions to the shift flight leader.

The physician responsible for medical monitoring performs detailed analysis of biotelemetry data, estimating the condition of the crew and reporting it to the shift flight leader.

As trajectory information is processed and orbital parameters are determined, the ballistic data are automatically transmitted to the control room displays.

The communications operator carries on planned radio conversations with the crew. The person responsible for the tracking stations monitors their operation and, if there is any deviation from the planned program, informs the shift flight leader and takes steps to eliminate deviations.

The onboard computer specialist monitors operation of the computer and, if necessary, prepares changes to the computer program which are then transmitted to the spacecraft.

The center shift leader monitors the operation of all services at the center and, if there are deviations in any operations, informs the shift flight leader and takes steps to eliminate them.

The shift flight leader, considering all the information which he receives, makes decisions concerning the future flight program. If there are no deviations in the operation of onboard and ground-based systems, permission is given to perform operations in accordance with the planned program.

If it is necessary to correct the program, the correction is made by the person responsible for planning the program. Correcting actions may be undertaken during a session or in subsequent sessions. If necessary in order to identify failures and test correcting actions, a mathematical model of the station or the combined spacecraft physical model may be used. Decisions are implemented by transmitting instructions by radio from the flight control center to onboard systems or by verbal transmission of instructions to the crew.

Control Room Operation Support

In addition to the major specialists in the control room, there are also support groups at the center. The specialists in these groups are located in separate rooms equipped with positions similar to those in the control rooms. The main tasks of these personnel are to provide:

- support to personnel in the control room with calculations and information which can be used to make decisions concerning the flight program;
- consultation with control room specialists and assistance to them in analyzing the operation of onboard systems;
- assurance of implementation of decisions made by the shift flight leader;
- support for the operation of the technical equipment at the center; and
- prospective flight planning.

The personnel include the following specialists:

- specialists in onboard systems preparing and transmitting to the display devices the necessary additional information to control room specialists;
- specialists in operational planning of the flight program, to prepare, if necessary, changes to the flight program;
- specialists in advanced planning of the flight program (1 week);
- specialists in coordination of tracking station operations;
- specialists in communications which support communications of the center with the spacecraft and tracking stations;
- specialists in ballistics, included in the main ballistic center staff and performing the necessary ballistic calculations to determine the orbit, zones of visibility, entry and exit of the spacecraft from the shadow, maneuvers, as well as data necessary for scientific experiments;
- onboard computer specialists;
- representatives of the search and rescue system, constantly ready to go to work in case of an emergency return of the spacecraft;
- the medical monitoring group, which regularly analyzes biotelemetry and maintains communications with the flight medical support center;
- a group which plans the program for the crew's day off, prepares music transmissions for the crew, radio conversations between the crew and their families, and cultural and scientific activities; and
- to provide consultations to the flight leaders during experiments sponsored by representatives of another Socialist nation, the flight control center includes a consultation group of specialists representing the sponsoring nation.

Training of Control Personnel

Before starting to work at the center, control personnel undergo a training cycle. Training is performed using the mathematical model of the Salyut space station, the physical model of transport spacecraft, and training machines. Actual tracking stations and communications devices are used in these training exercises. The crew of the Soyuz T spacecraft participate in the training as well.

Training exercises are performed under conditions as close to those of real flight as possible. The flight program is developed in real time with interactions among individual groups of control personnel, the flight control center, and the tracking stations. Nonstandard situations which may develop on board and on ground are simulated. The most difficult flight stages are run through repeatedly.

The Baykonur Kosmodrom

The Baykonur Kosmodrom is a complex organization with many branches, a combination of unique devices, automatic systems, and engineering structures serviced by specialists of many sorts.

The Baykonur Kosmodrom is located in the Kazakh SSR in a semidesert area with a continental climate

(hot, dry summer and cold, dry, windy winter). It was founded in 1955.

The reasons for selecting the location of the Kosmodrom were that it is remote from large populated areas, thus allowing safe rocket launches to be assured and separation zones (i.e., areas for the landing of returning spacecraft) to be set aside, and that many days in this area are cloudless.

Launches are performed from the Baykonur Kosmodrom in accordance with the national space research and utilization program of the U.S.S.R., in cooperation with other socialist nations in the "Interkosmos" program, and also in accordance with agreements for joint operations concluded with the United States, France, and other nations.

The world's first artificial Earth satellite was launched from the Baykonur Kosmodrom, the first cosmonaut Yu. A. Gagarin, and the first woman V. V. Tereshkova started from Baykonur; the Luna, Venera, Mars, and Zond automatic interplanetary stations were launched here, as were space stations and artificial Earth satellites of various types (Kosmos, Elektron, Polet), and the Molniya series of satellites used to relay television programs and to provide long-distance telephone and telegraph communications.

Manned Soyuz T spacecraft and Salyut orbital stations are regularly launched from the Baykonur Kosmodrom.

The Kosmodrom is used for assembly, testing, and launching of booster rockets with spacecraft, as well as for final prelaunch preparation of the cosmonauts.

The main component parts of the Kosmodrom are:

- the booster rocket assembly and testing building;
- the spacecraft assembly and testing building;
- the launch areas; and
- observation, command, and telemetry points.

The residential area of the Kosmodrom is located some tens of kilometers from the launch area and technical buildings. Here we find the cosmonaut training complex (classrooms for technical and scientific training of crews, the sports complex with swimming pool, laboratories to prepare the cosmonauts for flight, and the medical complex), as well as the institute, technical school, schools, club, stadium, television center, etc.

The Kosmodrom is connected to other points in the nation by air, highway, and rail. The territory of the Kosmodrom also has a well-developed network of highways and railroads.

The operations of assembly, testing, and joining of booster rockets and spacecraft are performed at the technical positions in the installation and testing buildings of the Kosmodrom, which are equipped with the necessary testing and measurement equipment and tools.

A number of launch and technical positions have been constructed at the Kosmodrom. One of the most important is the position from which three-stage booster rockets carrying the Vostok, Voskhod, Soyuz, and now Soyuz T spacecraft are launched.

The launch structure for this booster rocket includes a launch system with releasable supporting beams. The rocket is "suspended" in the launch system by the supporting units. The rocket system is delivered to the launch position from the assembly and testing building of this technical position, where it is assembled in the horizontal position.

The launch complex of the system, equipment, and engineering structures used to transport the rocket system to the launch position, set it in the launch structure, and perform prelaunch testing includes:

- the transporter and erector;
- the launch structures;
- the launch system (supporting frames and restraining devices; cables, hoses, and cable towers);
- the servicing devices (servicing frames and cabin); and
- the fuel and oxidizer supply systems.

The launch and other structures also contain: systems for filling and thermostatting fuel; a compressor station; compressed-gas receiver; fuel storage tank; a system to control both the preparation of the rocket for launch and the actual launch; the command point bunker, connected by communications lines to all operational services of the Kosmodrom; observation and command-measurement points; and the flight control center.

Preparation of the booster rocket for launch begins with transportation of its stages and sections of the spacecraft in special railroad cars from the manufacturing plants. The individual stages of the booster rocket are delivered to the spacecraft assembly building, where they are automatically tested, assembled, and prepared to be joined with the spacecraft. The spacecraft is assembled and tested in the spacecraft assembly building.

The ship is filled with fuel components and compressed gases at the filling station of the Kosmodrom, to which the spacecraft is delivered in a special railroad car. After it is filled and final operations are performed, the transit section and nose fairing are attached to the spacecraft. The assembled forward unit is then attached to the booster rocket, and the entire rocket-spacecraft system is tested.

This completes the work at the technical position, and the space system is delivered to the launch position on its transporter.

To install the rocket on the supporting beams of the launch system, the transporter raises the rocket to the

vertical position by means of hydraulic jacks. During this time the supporting beams are shifted from an inclined position to their operating position and accept the weight of the rocket in its central (supporting) belt. The rocket is thus suspended over the gas-deflecting trough. Its tail portion is several meters below ground level. This helps to protect equipment on the ground from the powerful high-temperature jet of the motors.

The transporter, after placing the rocket on the supporting beams, lowers its boom to the horizontal position and rolls away the launch system. The servicing booms, cable, and hose towers are brought up to the rocket. As soon as they are in their operating position the process of azimuthal guidance of the rocket and placement of the rocket in the strictly vertical position is begun. All of these operations are performed by mechanisms on command of the remote control system. The air system which controls the temperature of the spacecraft is then started up. The essence of this operation is feeding of air beneath the fairing of the booster rocket at a rate such that the apparatus and fuel components remain within a defined temperature range. The air thermostatting system continues operating almost up to the moment of launch.

After the various lines are connected (fuel, drainage, pneumatic, electrical) to the rocket and spacecraft, the next operation begins—pressure-testing, i.e., checking the tightness of seal of all connection points with compressed air. Any pressure drop indicates a leak.

The testing and launch apparatus then begins prelaunch testing of the onboard systems and units of the rocket. All onboard systems are tested to determine if they are functioning properly and their initial conditions are correctly set; individual onboard and ground-based instruments are checked (without starting the standard programs or turning on the actuating organs); the television, communications, command radio link, onboard power supply, and other systems are tested. The results of prelaunch testing are displayed on all video-monitoring devices and recorded by the telemetry systems and multichannel recording machines. If all onboard system and unit parameters are normal, permission is given to begin fueling the booster and filling its compressed-air tanks.

The transfer of liquid oxygen into the booster is a special operation. The lines and tanks are first cooled; i.e., their temperature is artificially reduced to prevent the liquid oxygen from boiling off and to reduce the pressure in the booster's tanks and lines. For this purpose a small quantity of liquid oxygen is fed in from the storage container. As it evaporates, it cools the tanks and lines then passes through the safety and drainage valves in the gaseous state. After the tanks and lines are cooled, the pumps begin to operate. The level-monitoring system (SKU) assures precise measurement of fuel components.

Control of the filling process and monitoring of the transmission of instructions are performed remotely from the launch-pad command point.

At the same time as the booster rocket and the spacecraft are fueled, their systems, instruments, and units undergo final testing, adjustment, and simulated operation, and commands are transmitted to the memory unit of the onboard control system—it is set up to perform a definite program of orbital insertion.

Since liquid oxygen evaporates it must be topped off; i.e., additional liquid oxygen is pumped in to fill the tanks to the required level. The fuel components are then drained from the filling lines, after which the filling, drainage, and pneumatic lines are disconnected, and the correct vertical position and azimuthal guidance of the rocket are tested.

Two hours and thirty minutes before the launch the cosmonauts take their places in the spacecraft. The final prelaunch and launch operation program is started. The automatic system assures a launch at the precise time with an accuracy of a few hundredths-of-a-second. Final monitoring of all rocket system before the launch is performed by telemetry.

At minus 1 minute, when it becomes clear that all systems and units of the booster rocket and spacecraft are operating properly and the cosmonauts are ready for the launch, the operator places a switch in the "launch" position. The automatic final launch-operation program is started. Operations performed are displayed on the control panel. The fuel-and oxidizer-tank drainage lines are closed at this time. The cable and hose towers swing away from the rocket. The turbine pumps begin operating. The ignition is turned on. The pyrotechnic ignition devices create flames in the chambers of the first- and second-stage motors. The motors develop thrust, operating in the preliminary, intermediate, and then main operating modes. When the motor thrust exceeds the weight of the booster rocket it begins to rise and is freed from the clamps of the launch system support beams. At this instant a contact closes and the "launch" light begins to shine on the control panel. Information on the prelaunch preparation and insertion of the spacecraft into orbit is sent to the flight control center, where it is processed and displayed on the common and individual screens in the control rooms. Control of the

spacecraft is transferred from the launch complex to the flight control center immediately after separation of the third stage of the booster rocket.

Command, Measurement, and Search and Rescue Systems

The flight of the Soyuz T spacecraft is controlled through the U.S.S.R. command and measurement complex, based on seven tracking stations in the Soviet Union—Dzhusaly, Yevpatoriya, Ussurisk, Ulan-Ude, Kolpashevo, Tbilisi, Petropavlovsk-Kamchatskiy, U.S.S.R. Academy of Sciences research vessels in the Atlantic and Pacific Oceans, and the USSR Academy of Sciences computer centers. These ground-based and ocean tracking stations are located so as to provide communications with the station and transport spacecraft in all orbits of the flight.

The longest continuous communications with the crew are provided for those orbits when the spacecraft dock, the crew move out for a space walk, or the spacecraft begins its return from orbit.

Command program information is transmitted from the control center to the tracking stations through automated telephone communications lines and is relayed from there to the orbital station. Telemetry and television information can also be recorded at the tracking stations for subsequent transmission to the flight control center.

The ground-based complex is a component part of the Salyut space station and Soyuz T spacecraft flight control loop. The control loop includes: the flight control center, ground-based and shipboard tracking stations, the ground and satellite communications system, and ballistic centers.

As it controls the flight, the ground-based control complex performs the following tasks:

- exchange of all types of information between the spacecraft and the flight control center;
- provision of two-way telephone and telegraph communications between the control center and the spacecraft crew;
- measurement of the parameters of the spacecraft's motion;
- organization of communications between elements of the ground-based control system and the flight control center; and
- operational administration and coordination of operation of tracking stations and other elements of the ground-based system.

The tracking stations in the process of a flight measure the parameters of the spacecraft's motion and receive telemetry and television information from the spacecraft. All decisions related to flight control are implemented through the tracking stations by conducting conversations with the crew and transmitting radio commands to the spacecraft.

There are about 20 telephone and telegraph communications channels between the center and a typical tracking station. Most tracking stations have wideband communications channels with the center. The tracking station is equipped with a computer which can perform about 50,000 operations per second. Elimination of telemetry redundancy from the flow of telemetry information is performed by specialized apparatus. The throughput capacity of the data transmission apparatus used over the telephone channels is 2,400 bps.

Shipboard command and measurement points receive and transmit to the center the complete flow of telemetry information from the spacecraft. Molniya communications satellites are used in the satellite communications system.

The tasks of the search and rescue complex include:

- search for and location of the returning spacecraft and cosmonauts,
- determination of the coordinates of their landing,
- evacuation of the cosmonauts and provision of medical aid,
- technical servicing of the spacecraft, and
- its removal from the landing area to its assigned point.

The men and equipment of the search and rescue complex are placed where the returning spacecraft will land. Helicopters and aircraft, observing the spacecraft visually and by radio, converge on their assigned locations along the landing track, using radio direction finding to approach the spacecraft and accompany it as it comes in for a landing, and maintain two-way communications with the crew.

The returning spacecraft land in a selected area of the Soviet Union. The descent apparatus is designed to land on dry land; the apparatus has special systems assuring safety of the cosmonauts should it land in water.

In the landing area the cosmonauts are met by a specially trained search group. This group includes technical specialists and physicians. The search group is provided with everything necessary to reach the landing point rapidly and to provide any needed assistance to the cosmonauts.

The search aircraft carry parachute personnel including physicians and rescue specialists who if necessary parachute to the spacecraft after it lands. Search and rescue equipment includes aircraft and helicopters, ships and all-terrain vehicles. The technical specialists and physicians included in the search group are well-trained parachute jumpers and scuba divers. The physicians of the group have available the necessary medical equipment and medications, adapted for use under any weather conditions.

After landing, the cosmonauts open the hatches of the spacecraft and prepare containers of scientific apparatus and photographic film for transportation. If necessary they can use the reserve stores onboard the spacecraft, including warm clothing, swimsuits, signaling and radio communications devices, extra water, and other necessary products. After landing and leaving the spacecraft, the cosmonauts take off their spacesuits and put on flight clothing. The containers of scientific apparatus and film are turned over to the specialists in the search group. The cosmonauts undergo post-flight physical examination at the landing point.

If the spacecraft lands in water, the cosmonauts remove their spacesuits, don special equipment, prepare to use their flotation devices, and maintain contact by radio with the search service. The search group which arrives at the landing zone helps the cosmonauts to leave the spacecraft.

The search process, location of the spacecraft, and evacuation of the cosmonauts from the spacecraft and from the landing zone are all reported from the area in which the search and rescue complex operates to the flight control center.

The Yuriy Gagarin Cosmonaut Training Center

The Yuriy Gagarin Cosmonaut Training Center (TSPK) was created in 1960 and is located outside Moscow, in Zvezdnyy Gorodok [Star Village].

The cosmonaut training center is an institution provided with modern equipment and manned by qualified specialists, capable of training crews for space and expeditions in accordance with the increasing demands of the time.

The specialists at the Center have accumulated great experience in educational, scientific, and indoctrination work. They take part in studies of the prospects of using manned spacecraft, and contribute to the improvement of spacecraft and their equipment and to the planning of future flights.

The structure of the TSPK, the mission of its main subunits, and [the composition of its] professional staff of specialists are determined by the tasks which it performs in preparing and supporting space flight.

In 1968 the Center was named in honor of Yuriy Gagarin.

In 1971, for its great services in the preparation of crews for spaceflight, its participation in the mastery of space, and in connection with the 10th anniversary of the world's first manned space flight, the center was awarded the Order of Lenin.

During the operation of the TSPK (up to June 1, 1982) 49 manned spacecraft crews were trained, including: 6 for the Vostok spacecraft, 2 for the Voskhod spacecraft, 37 for the Soyuz spacecraft, 4 for the Soyuz T spacecraft. Sixty cosmonauts had been in space, including 10 three times (Vladimir Shatalov, Aleksey Yeliseyev, Valeriy Bykovskiy, Petr Klimuk, Nikolay Rukavikhnikov, Valeriy Kubasov, Valeriy Ryumin, Viktor Gorbatko, Oleg Makarov, Vladimir Kovalenok), and 15 twice, as well as 9 cosmonauts who were citizens of other Socialist nations: Vladimir Remek (CSSR), Miroslav Germashevskiy (Poland), Zigmund Jen (GDR), Georgiy Ivanov (Bulgaria), Vertalan Farkash (Hungary), Fam Tuan (Viet Nam), A. Tamayo Mendes (Cuba), Zhugderdemidiyn Gurragcha (Mongolia), and Dumitru Prunariu (Roumania).

In 1980 the cosmonaut training center celebrated its 20th anniversary.

Appendix B

Soviet Space Stations: Achievements, Trends, and Outlook

Geoffrey E. Perry, MBE
November 1982

My mathematical conclusions, based on scientific data verified many times over, show that with such devices it is possible to ascend into the expanse of the heavens, and perhaps to found a settlement beyond the limits of the Earth's atmosphere. . . . People will take advantage of this to resettle not only all over the face of the Earth but all over the face of the Universe. . . .

—K. E. Tsiolkovsky 1903

It is a widely held belief that the Soviet space program deliberately follows the paths described in the early years of the century by Konstantin Tsiolkovsky.[1] Be that as it may, it is certainly possible to find close parallels between Tsiolkovsky's writing and the course of events, but more likely these parallels result because modern engineers have arrived at similar solutions to the same problems rather than because of slavish obedience or preconceived notions.

Smolders[2] holds that the concept of space stations forms the nucleus of Tsiolkovsky's vision of space travel. Tsiolkovsky considered the construction of a permanent base in space to be the first important step towards a landing on the Moon and exploration of the planets. A space station concept attributed to Tsiolkovsky depicting a closed ecological system and garden, laboratories, living quarters, and a docking port with an airlock has been reproduced in official Soviet publications. Illustrations of other space stations appearing on commemorative stamps owe more to the designs of Shternfel'd and others which are to be found in a handbook produced by the staff of the Battelle Memorial Institute.[3] A 1964 Soviet Defense Ministry book on *Manned Space Stations* listed the building of a larger manned space station, with a crew of 30 to 50, in the 1972-75 period, as the third of five further stages in space conquest.[4] To date, the maximum number to man a complex at any one time has been five for the Apollo-Soyuz mission and two visits to Salyut 7.[5]

After the "troika" mission of Soyuz 6, 7, and 8 in 1969, Leonid Brezhnev said, "Soviet science views orbital stations with interchangeable crews as man's major highway into space. . . . Major scientific laboratories will appear for conducting research in space technology and biology, medicine and geophysics, astronomy and astrophysics."[6]

According to Feoktistov and Markov, direct work on Salyut space stations began in 1969.[7] To reduce cost and to shorten the construction time as many units and separate systems as possible were used from Soyuz, Zond, and other tried and tested designs. Most of these needed modification as they did not provide the required service-life, and basic systems, such as the heat supply, were built from scratch. The intention of using the manned mode opened up the possibility of in-orbit repair and replacement of defective subsystems, thereby increasing the reliability and life of the station.

A study of Soviet space station philosophy demands consideration of Salyut, Soyuz, and Progress spacecraft as components of an orbital complex. The Soyuz acts as a manned transport craft between Earth and the orbiting space station, remaining docked with the station whilst the crew is on board, in the same manner as the Apollo was used for three missions to Skylab and, presumably, the Shuttle orbiters will be used with any future National Aeronautics and Space Administration (NASA) space station. Progress, a Soyuz derivative, has an unmanned role as an expendable cargo vehicle.

[1] V. Rich, *Nature* 250 (London: July 19, 1974), p. 177.

[2] P.L. "Soviets in Space" (Guildford: Lutterworth Press, 1973), p. 34.

[3] G. E. Wukelic (ed.), *Handbook of Soviet Space-Science Research*, Gordon and Breach, New York, 1968, pp. 473-486.

[4] I. N. Bubnov and L. N. Kaminin, "Manned Space Stations," *Voyennoye Izdatel'stvo Ministerstva Oborony SSSR* (Moscow: 1964) and quoted in M. Stoiko, "Soviet Rocketry," p. 209.

[5] *Apollo*, Thomas Stafford, Donald Slayton, and Vance Brand. *Soyuz*, Aleksey Leonov and Valeriy Kubasov. Docked 1309 Z, July 17, 1975. First undocking 1203 Z, July 19. 37 min. undocked. Second docking 1240 Z, July 19. Final undocking 1526 Z, July 19, 50 hr. 17 min. total, 49 hr. 40 min. net. *Soyuz-T 5*, Anatoliy Berezovoi and Valentin Lebedev. *Soyuz-T 6*, Vladimir Dzhanibekov, Aleksandr Ivanchenkov, and Jean-Loup Chretien. Docked 1746 Z, June 25, 1982. Undocked 1101 Z, July 2, 161 hr. 15 min. total. *Soyuz-T 7*, Leonid Popov, Aleksandr Serebrov, and Svetlana Savitskaya. Docked 1832, Aug. 20, 1983. Undocked 1145 Z, Aug. 27, 161 hr. 13 min. total.

[6] Brezhnev's statement quoted by A. S. Yelisayev at press conference following end of manned phase of the Salyut 6 mission, reported in *Izvestiya*, July 14, 1981, p. 2, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, p. 4.

[7] K. P. Feoktistov and M. M. Markov, "Evolution of 'Salyut' Orbital Stations," *Zemlya i Vselbnnya*, 5, September-October 1981, pp. 10-17, reproduced in JPRS 80424, Space No. 15, Mar. 29, 1982, p. 1.

Although certain events in the history of the Soviet space program have been spectacular at the time, it must be realized that they are not instant technological breakthroughs but rather are the results of careful planning and cautious steps towards the desired goals. The docking of the Soyuz 4 and 5 spacecraft in 1969, claimed as establishing "the world's first orbital space station,"[8] should be seen as the first docking of two manned Soviet spacecraft following two successful automatic dockings of unmanned satellites in the Cosmos series.[9] The clue to the intended function of the Soyuz was to be found in the name "Union," although a characteristic element of ambiguity was also present. The EVA transfer of cosmonauts between the two spacecraft demonstrates the step-by-step approach and unsophisticated design philosophy.[10] Internal crew transfer was not accomplished until Soyuz 11 docked with Salyut 1 more than 2 years later.

The Soyuz T (T = transport) currently in use with the Salyut 7 space station has evolved through several variants. Tested unmanned in the Cosmos series, Soyuz 1 malfunctioned and killed cosmonaut Komarov during the return to Earth when the parachute failed to deploy correctly.[11] This resulted in an 18-month period of redesign before testing recommenced with the unmanned rendezvous and docking of Cosmos 186 and 188. As in Voskhod, crews flew without spacesuits and a three-man capacity was demonstrated with Soyuz 5 although, for the Soyuz 9 recordbreaking 18-day flight, the crew was reduced to two to permit sufficient consumables to be carried. The loss of the crew of Soyuz 11 returning from the 24-day mission to Salyut 1 necessitated a further period of redesign.[12] To accommodate a life-support system and a spacesuited crew, one of the seats was removed and Soyuz flew as a two-man spacecraft for the remainder of its life, ending with Soyuz 40 in 1981.[13]

Prior to this, unmanned flights in the Cosmos series, having characteristics similar to those of manned missions, pointed to the development of a new manned spacecraft.[14] It was mildly disappointing when, on its first flight to the Salyut 6 space station at the end of 1979, it was named Soyuz T and then shown in photographs to have the same external shape and dimensions of the old Soyuz.[15] Internal redesign has restored the three-man capacity,[16] whilst permitting the use of spacesuits at critical phases of the mission, and an onboard computer has enhanced its performance. Whereas the early Soyuz spacecraft were stated to have a 30-day capability, Soyuz T 5 functioned in orbit for 106 days, during which it was docked with Salyut 7 for 103 days.[17]

A major disadvantage of using the Soyuz appears to be the tight constraint imposed by lighting conditions during recovery. Information released at the time of the Apollo-Soyuz Test Project (ASTP) revealed that landings should occur at least 1 hour before local sunset and that a minimum of 8 minutes should elapse between eclipse-exit and retrofire. Graphical analyses by Christy[18] and Clark[19] show that the 31 revolutions repeating pattern of ground tracks employed for the Salyuts 6 and 7 lead to landing "windows" at intervals of approximately 2 months. Moreover, the duration of these windows varies from only 7 to 10 days depending on the time of year. These windows, in turn, impose constraints on mission durations. The 8-day Intercosmos missions, for example, were launched immediately prior to the opening of a landing window so that, if the need to abort prematurely should arise, as with the Bulgarian mission, the constraints could be obeyed on the third day.[20] To date, Soyuz T spacecraft have also obeyed these constraints and have yet to demonstrate the capability to make normal landings at any time of the day or night. If this practice is followed for Berezovoi and Lebedev, then the next window opening around the end of the year would prolong their mission to something in excess of 230 days.[21] The constraints could be obeyed in an emergency at other times of the year by moving the recovery zone from the Kazakhstan region. Cosmonauts have been depicted training for recovery from landings in water should such landings prove to be necessary.[22]

Up to a few years ago, the orbital module remained attached to the command module until after retrofire.

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[8]Phrase used in a question by the *Tass* correspondent at Cosmonauts' press conference in Moscow, Jan. 24, 1969, reported in SU/2984/C/4.

[9]*Cosmos 186* launched Oct. 28, 1967. *Cosmos 188* launched Oct. 30: First orbit rendezvous and docking at 0920 Z, Oct. 30. Undocked at 1250 Z; 3 hr. 30 min. total time docked. *Cosmos 212* launched Apr. 14, 1968. *Cosmos 213* launched Apr. 15: First orbit rendezvous and docking at 1021 Z, Apr. 15. Undocked at 1411 Z; 3 hr. 50 min. total time docked.

[10]*Soyuz 4*, Vladimir Shatalov, launched Jan. 14, 1969. *Soyuz 5*, Boris Volynov, Yeugeniy Khrunov, and Aleksey Yeliseyev, launched Jan. 15: 18th orbit rendezvous and docking at 0820 Z, Jan. 16. Undocked at 1255 Z; 4 hr. 35 min. total time docked.

[11]*Soyuz 1* with Vladimir Komarov crashed Apr. 24, 1967.

[12]Soyuz 11 landed on June 29, 1971; its three crewmen, Georgiy Dobrovolskiy, Vladislav Volkov, and Viktor Patsayev, perished.

[13]*Soyuz 40* landed May 22, 1981.

[14]*Cosmos 1001* launched Apr. 4, 1978, recovered after 11 days; *Cosmos 1074* launched Jan. 31, 1979, recovered after 60 days.

[15]*Soyuz-T* launched Dec. 16, 1979.

[16]*Soyuz-T 3*, Leonid Kizim, Oleg Makarov, and Gennadiy Strekalov launched Nov. 27, 1980.

[17]*Soyuz-T 5* landed Aug. 27, 1982.

[18]R. D. Christy, "Safety Practices for Soyuz Recoveries," *Spaceflight* 23, 1981, pp. 321-322.

[19]P. S. Clark, "Soyuz Missions to Salyut Stations," *Spaceflight* 21, 1979, pp. 259-263.

[20]Soyuz 33, Nikolay Rukavishnikov and Georgiy Ivanov, Apr. 10-12, 1979.

[21]*Soyuz-T 7* landed in poor conditions at night, Dec. 10, 1982, 211 days 9 hr. 5 min. record duration.

[22]*Spaceflight* 20, 1978, p. 305 shows Aleksey Gubarev and Vladimir Remek practicing for Soyuz 28.

Latterly, it has been jettisoned prior to retrofire.[23] The orbital module, filled with bulky, used equipment, burns in the atmosphere on reentry and provides a means for disposing of unwanted material as an alternative to the regular use of the airlocks. The unloaded Progress performs a similar function but is deorbited over the Pacific rather than being left to decay naturally. The crew capacity of the Soyuz T is limited to three by the use of the A-2 vehicle for its launch. This booster, using the same first stage as that used to launch the first Sputnik 25 years ago, is the only Soviet booster to be man-rated to date. The large D vehicle now appears to be totally reliable and could possibly be man-rated at some future date for launching spacecraft with larger crew complements, and some Western observers speculate that the mysterious dual payload launches at 51.6° inclination were reentry tests of reusable winged spacecraft.[24] The Cosmos 1374 mission of summer 1982 has been claimed to have been a reentry test of a scale model winged spacecraft, launched by the intermediate capacity C vehicle; the Royal Australian Air Force released pictures of the follow-on Cosmos 1445 spacecraft being recovered from the Indian Ocean.[25] Nevertheless it is not unreasonable to suppose that research and development work leading to a reusable manned spacecraft to service a permanently manned space station is in hand.

The unmanned Progress craft is something more than an interim measure to provide space-station crews with fresh supplies. The Soviets have mastered the technique for resupplying their Salyut stations with propellant and potable water, a feat unmatched in the Skylab missions and, as yet, unnecessary for the space Shuttle. Moreover, the residual propellant of the Progress engine has been used to maneuver the Soyuz-Salyut-Progress orbital complex in the manner of a primitive space tug.[26]

The altitudes selected for the Salyut missions below the Van Allen radiation belts[27] are not the most economical in terms of propellant usage. The relatively high air-drag, particularly in the case of the "military" Salyuts 3 and 5,[28] made great demands on stored propellants to maintain the orbit throughout the duration of the missions. Choice of a greater altitude to minimize propellant consumption exacts a penalty in terms of surface resolution for Earth observation programs. As space stations increase in physical size and complexity the drag problem will attain an even greater significance.

The small interior volume of the Salyut stations, which have an effective floor-area of 16 square meters[29] in the working compartment, must lead to cramped conditions, especially at times when the cosmonauts are joined by visiting crews. A first step towards increasing the interior volume came with the docking of Cosmos 1267, a "prototype space module,"[30] with Salyut 6. Although this docked complex was never manned, it was claimed[31] that future stations could be enlarged by docking with modules dedicated to different disciplines including crew rest and relaxation. The Cosmos 1267 engine was used to maintain the Salyut 6 orbit[32] and eventually to deorbit the docked complex at the close of the joint mission.[33] Cosmos 1267 and its predecessor, Cosmos 929, were both reported to have returned part of their structure to Earth after a period of some 30 days.[34] Salyuts 3 and 5 also returned capsules during the unmanned phases of their missions, and thus an unmanned return capability already can be seen to exist.[35]

Another disadvantage of the current Salyut program is the lack of near-continuous communication with ground stations. For long periods in each orbit the crew is out of touch with ground control. In the initial stage of Soviet manned spaceflight this disadvantage was partially overcome by the use of shortwave frequencies for voice communication as well as the long-range housekeeping telemetry still in use today. Later, merchant ships were converted to provide communication links through Molniya satellites,[36] and purpose-built vessels have since modernized the space support fleet maintained by the U.S.S.R. Academy of Sciences.[37]

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[23] Orbital module of first Soyuz-T discarded 25 March 1980, catalogued by RAE as 79-103D but as 77-97BR by NORAD.

[24] *Cosmos 881-82*, Dec. 15, 1976; *Cosmos 997-998*, Mar. 29, 1978; *Cosmos 1100-1101*, May 22, 1979; and T. Williams, "Soviet Re-entry Tests: A Winged Vehicle?" *Spaceflight* 22, 1980, pp. 213-214.

[25] *Aviation Week & Space Technology* 116, June 14, 1982, p. 18, and *Cosmos 1374*, June 3, 1982. (Pictures of the 1983 flight of Cosmos 1445, a similar spacecraft, taken by the Royal Australian Air Force have been published by the world's media.)

[26] ". . . during the joint flight the engines of Progress 15 had been used to make two adjustments of the trajectory of the orbital complex." (*Tass* in Russian for abroad, 1436 GMT, Oct. 14, 1982, reported in SU/7163/D/3.

[27] Explorer 1 discovered radiation belt at 950 km.

[28] *Salyut 3*: 256-292 km. Salyut 5: 214-257 km.

[29] Yu Semenov and L. Gorshkov, "'Salyut 6' Orbital Station: Home, Laboratory, Vehicle," *Nauka i Zhizn'*, April 1981, pp. 43-53, 125, reproduced in JPRS 78779, Space #12, Aug. 19, 1981, p. 7.

[30] Cosmos 1267 docked with Salyut 6 at 0752 GMT, June 19, 1981. *Moscow Home Service*, 0930 GMT, June 19, 1981, reported in SU/6735/D/1.

[31] Interview with Konstantin Feoktistov, UPI, 1248 GMT, June 24, 1981; and interview with Konstantin Feoktistov, *Tass*, Russian for abroad, 0506 GMT, June 24, 1981, reported in SU/6770/D/1.

[32] *Moscow Home Service*, 1400 GMT, July 1, 1981, reported in SU/6770/D/1.

[33] *Tass*, Russian for abroad, 1057 GMT, July 29, 1982, reported in SU/7095/D/1.

[34] "Part of New Soviet Space Station Deorbited and Recovered," *Defense Daily*, May 29, 1981, p. 153. (Cosmos 1267 capsule returned May 24, 1981.)

[35] Salyut 3 returned capsule on Sept. 23, 1974, *Tass*, Russian for abroad, 1405 GMT, Sept. 26, 1974, reported in SU/4715/C/1 and Salyut 5 returned capsule on Feb. 26, 1977, *Tass* in Russian, 1502 GMT, Mar. 2, 1977, reported in SU/5458/C/1.

[36] Tass in English, 0900 GMT, Oct. 18, 1969, reported in SU/3207/C/2.

[37] G. Bezborodov and A. M. Zhakov, "Suda Kosmicheskoy Sluzhby," *Izdatel'stvo "Sudostroyeniye,"* (Leningrad, 1980), reproduced in JPRS L/9862, Space FOUO 3/81, pp. 1-21.

Details of an Eastern Satellite Data Relay Network (ESDRN) lodged with the International Frequency Registration Board in 1981[38] show that the Soviet Union intends to operate a system employing frequencies in the Ku-band[39] similar to the American TDRSS for communicating with Salyut stations and other spacecraft in low-Earth orbit, commencing no sooner than December 1985.

Following the end of the manned phase of the Salyut 6 mission in 1980, articles appeared in the daily and technical press detailing the achievements and outlining future needs.[40] Isvestiya stressed that those achievements were not only in the great reliability and longevity in space of the onboard systems and equipment but also in the vast amount of experimental work aimed at finding solutions for fundamental scientific problems and practical requirements on Earth today. The requirements of 22 of the Ministries and Departments of the U.S.S.R. were considered.

More than 1,600 experiments were said to have been performed involving some 150 items, many of which were repeated at least once.[41] Of these, 60 were astrophysical, 200 on the production of materials of exceptionally high purity, and 900 in medicine and biology. Many of the latter were in cooperation with other countries as part of the Intercosmos program. The superpure materials ranged from the homogenous alloys and semiconductor materials, produced in the Kristall, Splav, and Isparitel furnaces and ovens,[42] to vaccines produced by electrophoresis.[43] Much time was devoted to the observation of the Earth from space. Some 13,000 photographs were obtained using the Kate-140 topographical and MKF-6M multispectral cameras.[44] As a result, a supply of freshwater was located in the Kyzyl-Kum desert and large-scale geological features coinciding with mineral deposits and possible oil-bearing regions were identified.[45] It was stated that photographs of an area covering 1 million km² could be recorded on film in 10 minutes, equivalent to the result of several years' aerial photography.[46] (Salyut 4 was reported to have returned photographs of 4.5 million km² of the U.S.S.R.)[47] In addition to radioastronomy, experiments with the KRT-10 in 1979,[48] astronomical observations of active areas of the Sun's surface and other X-ray sources were made and infrared radiation from the planets and stars was recorded using the cryogenically cooled 1.5-meter diameter BST-1M telescope.[49] For these observations an orientation accuracy of a few arc seconds was maintained,[50] and some Western commentators have seen military implications related to the pointing of directed-energy weapons in this context.[51] Undoubtedly, there is a large area in which military and scientific experimental programs overlap each other.

Experience has shown that it is possible for crews to work in space for long periods at a time so long as they follow a regular exercise regime[52] to counteract the effects of prolonged weightlessness. Equally important is sustaining the psychological well-being of the crew.[53] To this end consideration has been given to the interior decoration of the station.[54] It was found that working to a normal Earth time schedule was beneficial both to the cosmonauts and the ground-support teams. Regular rest days at weekends are used for housekeeping and relaxation. The introduction of a two-way television link[55] enabling the cosmonauts to see their families whilst talking to them at the weekends was a great morale-booster as were the visits from short-term crews. However, the strain began to tell on the Salyut 7 cosmonauts who set the record of 211 days in space, and their working day was reduced from 16 to 12 hours.[56]

And what of the future? Steps must be taken to overcome the disadvantages of the current program mentioned above. More efficient transport crafts are needed. A Soyuz can deliver only 50 kg of supplies in addition to its crew, and Progress is limited to 2,300 kg.[57] Although Progress transports delivered more than 20 tonnes of supplies to Salyut 6 in 12 visits, the greater part of the cargo comprised life-support system supplies and units, fuel and replacements for onboard systems.[58] A man requires more than 10 kg of replacement life-support system elements every day,[59] and

[38]Special Section No. SPA-AA/343/1484 annexed to IFRB Circular No. 1484, Sept. 1, 1981.

[39]10.82, 11.32, 13.7 and 13.52 GHz downlink; 14.62 and 15.05 GHz uplink.

[40]Feoktistov and Markov, idem., and Semenov and Gorshkov, idem., and "Looking to Orbits of the Future," *Isvestiya*, July 14, 1981, p. 2, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, pp. 3-6; and K. Feoktistov, "To Future Orbits," *Pravda*, June 9, 1981, p. 3, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, pp. 45-46.

[41]Ibid., p. 46.

[42]Semenov and Gorshkov, idem. p. 9.

[43]Feoktistov and Markov, idem., p. 11.

[44]Feoktistov, idem., p. 46.

[45]Feoktistov and Markov, idem., p. 4.

[46]A. P. Aleksandrov, *Isvestiya*, July 14, 1981, p. 2, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, p. 3.

[47]Feoktistov and Markov, idem., p. 4.

[48]N. S. Kardashev, A. I. Savin, M. B. Zakson, A. G. Sokolov, and K. P. Feoktistov, "The First Radio Telescope in Space," *Zemlya i Vselennaya*, No. 4, July-August 1980, pp. 2-9, reproduced in JPRS 76578, Space #7, Oct. 8, 1980, pp. 1-15.

[49]Feoktistov and Markov, idem., p. 6.

[50]Feoktistov, idem., p. 46.

[51]"Washington Round Up," *Aviation Week & Space Technology* 117, No. 17, Oct. 25, 1982, p. 15.

[52]Semenov and Gorshkov, idem., p. 15.

[53]N. Novikov, "An Extended Expedition," *Sovetskiy Voin*, No. 8, 1981, pp. 29-29, reproduced in JPRS 78779, Space #12, Aug. 19, 1981, pp. 26-29.

[54]Ibid., p. 8.

[55]Idem., p. 28.

[56]*Moscow World Service* in English, 1000 GMT, Oct. 27, 1982, reported in SU/7182/D/1.

[57]Novikov, idem., p. 27.

[58]Feoktistov and Markov, idem., p. 10.

[59]Ibid., p. 9.

there is an obvious need to change over to a new life-support system operating on a closed cycle, thereby eliminating the need to deliver water and atmospheric purification supplies. (A water-regeneration system did not produce in excess of 500 liters of potable water on Salyut 6.)[60] A reduction in the amount of fuel necessary for station orientation could be effected by the adoption of an electromechanical orientation system.[61] (Trials of this type of system were conducted on Salyut 3 and must be presumed to have been less than satisfactory since this principle has yet to be adopted operationally.)

The introduction of a new onboard computer system for Salyut 7 has relieved the crew of much routine work connected with the operation of the station.[62] This is markedly noticeable in communication sessions with ground control. On previous missions much time was spent in calling "Zaria," the ground control, in order to confirm that two-way contact had been established. Today, the computer switches on the transmitter when the stations rises above the radio horizon of the ground station, and the cosmonauts speak from wherever they chance to be in the station at the time. Feoktistov, commenting on the introduction of computer and microprocessor technology, has cautioned that enthusiasm for automation can lead to extraordinary complexity and, consequently, a reduction of equipment reliability.[63]

The elimination of the need to mothball the station between periods of occupancy by long-term crews would be a logical step in the steady evolution of Salyut operations. A further improvement would be the provision of facilities for receiving water and propellant from Progress transports at either of the two docking ports. This would eliminate the transportation and redocking which has hitherto been necessary to relocate the Soyuz at the forward docking port in order to accommodate a Progress at the aft port. Such redesign may also encompass provision of nonaxial docking ports although destruction of axial symmetry could introduce problems in maneuvering and altitude control.

In the distant future one might expect the Soviets to take steps to establish a permanent space station in geosynchronous orbit[64] for the collection of solar energy, its conversion to electrical energy, and transmission to Earth by microwaves, but these possibilities introduce difficulties several orders of magnitude greater than those solved to date.

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[60]Feoktistov and Markov, idem., pp. 10-11.

[61]Idem., p. 11.

[62]*Moscow Home Service*, 1800 GMT, May 21, 1982, reported in SU/7034/D/2, and *Moscow Home Service*, 0200 GMT, May 23, 1982, reported in SU/7048/D/2, and *Isvestiya*, July 16, 1982, reported in SU/7122/D/3.

[63]Feoktistov and Markov, idem., p. 10.

[64]Idem., p. 11.

Appendix C

OTA Workshop on Soviet Space Station Activities

List of Outside Participants

Craig Covault
Aviation Week & Space Technology

Leonard David
National Space Institute

Merton Davies
The Rand Corp.

Ed Ezell
Smithsonian Institution

John R. Hilliard
Air Force Systems Command

Nicholas Johnson
Teledyne Brown Engineering

Saunders Kramer
Department of Energy

Courtland S. Lewis
Biotechnology, Inc.

James Oberg
McDonnell Douglas Astronautics Company

Geoffrey Perry
The Kettering Group
Northants, England

Paul Rambaut
NASA Headquarters

P. Diane Rausch
NASA Headquarters

Marcia S. Smith
Congressional Research Service

Additional Reviewers

Hubert Bortzmeyer
Christopher H. Dodge
Russell Drew
Paul Hanle
Thomas Karas
Charles Kelly
Gordon Law
John Logsdon
George Mueller
Joseph Rowe
Carl Sagan
Charles P. Vick
Ray A. Williamson
Simon P. Worden

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SOVIET SPACE ACTIVITIES: IMPACT ON U.S. SPACE POLICY

by Marcia S. Smith

The Reagan Administration, like that of President Carter, is conducting a review of U.S. space policy for both the civilian and military programs. One facet of U.S. space policy that has received little mention is the role of Soviet space activities in shaping U.S. programs. After all, it was the Soviet lead in space that propelled the United States into the space age and led to the writing of the 1958 National Aeronautics and Space Act. The spaceflight of Yuri Gagarin in April 1961 was an important factor in convincing President Kennedy to choose the space program as a vehicle for restoring confidence in American technological leadership—and led to the Apollo lunar program.

What, then, is the Soviet Union doing in space today?

Are they likely to confront us with a space spectacular on the order of Sputnik or Vostok I, and would it make any difference this time?

This is a brief review of current Soviet space activities and plans for the future (since they rarely announce their plans in advance, discussions of future activities must be considered speculative). It focuses on Soviet space activities as they might impact American space policy, so the discussion centers on issues that are likely to receive the most scrutiny in the United States this year: manned activities, planetary programs, and military activities. Space applications programs are not discussed because the primary U.S. issue in this area is whether government or private industry should be responsible for these programs—an issue that has no counterpart in the Soviet Union. The Soviets do not separate their space program into military and civilian components, so the question of combining such activities in the United States is also omitted.

MANNED SPACE ACTIVITIES

The early Soviet manned program was much like that of the United States. The Soviet Vostok program was similar to U.S. Mercury flights, and Voskhod and early Soyuz flights were roughly comparable to Gemini. A sad similarity between the programs was the tragic blows dealt to both countries in 1967. In January, the three-man crew of Apollo I was killed in a pre-launch fire; in April, the single occupant of Soyuz I was killed on impact with the earth when the parachute lines on his spacecraft became tangled during descent.

The 1960's was the era of the infamous "Moon Race", and when the two manned programs began again in October 1968, it was clear that the U.S. was in the lead. The first manned U.S. mission (Apollo 7) tested the Apollo command/service module in earth orbit, while the first Soviet mission was an orbital rendezvous between one manned and one unmanned ship, a feat accomplished by the Americans three years earlier. The race was won two months later when the Apollo 8 crew circumnavigated the Moon, followed seven months later by the first lunar landing. The Soviets turned their attention to Earth orbit.

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Space Stations

A popular topic of conversation today is whether the United States should build a space station as its next major manned space activity. The Soviets already have such a program, and have stated that their goal is to have a permanently occupied earth orbiting space station. They are well on their way to achieving that goal.

In 1971, the Soviets launched the world's first space station, Salyut 1. Since that time, six more Soviet space stations have been launched—four successfully. With each new station, new capabilities have been achieved. Three of the stations are classed as military, while the other four are considered to be civilian. The difference between the two modes of operation is that military space stations use military frequencies for communications, have only military personnel for crews, and are in lower orbits to facilitate reconnaissance activities. The civilian stations use civilian frequencies, mixed military/civilian crews, and are in higher orbits which allow earth resources photography as well as astronomical observations. A wide range of biological, materials processing, and other experiments are performed as well. In total, the Soviets have sent 28 crews to occupy the space stations (22 successfully).

This program has not been without its troubles and tragedies. The first crew sent to inhabit Salyut 1, Soyuz 10, docked successfully, but was unable to enter the space station because the hatch could not be opened. The Soyuz 11 crew successfully inhabited the station for 24 days, but died from asphyxiation during reentry when an improperly closed hatch on the Soyuz spacecraft allowed the cabin atmosphere to vent into space. The crew was not required to wear spacesuits. Since that time, cosmonauts have worn suits during launch and reentry, forcing a return to two-man crews because the Soyuz could not accommodate three men plus the bulky suits and associated systems. Ten years were required before a modified version of Soyuz appeared, which together with new spacesuits, could accommodate three-man crews again. Five more of the crews sent to space stations did not dock successfully.

The statistics which the Soviets have accumulated recently in manned spaceflight are impressive, especially when compared with U.S. manned space activity. The last U.S. flight of the Apollo era was the July 1975 Apollo-Soyuz Test Project, a cooperative project with the Soviet Union. At the conclusion of ASTP, the U.S. had a cumulative total of 22,504 hours in space, while the Soviets had 10,740 hours. There were no more U.S. manned flights until the April 1981 flight of Space Shuttle Columbia

—a six year hiatus. During that time, the Soviets made 21 manned flights (18 of which were successful), all but one of which ferried crews to space stations. The 84-day duration record of Skylab 4 was broken by the Soviets in 1977 with the 96-day mission of Soyuz 26, and was successively increased to a duration of 185 days by the Soyuz 35 crew in 1980. From April to December 1981, the U.S. made two flights of the Space Shuttle and the Soviets made one more flight to a space station. By the end of 1981, the cumulative hours in space were: U.S.—22,721 hours; USSR—51,233 hours.

One of the greatest successes of the Soviet space station program is Salyut 6. Launched in September 1977, the station is still in orbit and functioning as of February 1982. The most significant improvement on Salyut 6 is its second operational docking port which allows two spaceships to dock with the station at one time. As a result, the ferry ship for the crew can remain docked at one end, while ships carrying supplies or additional crews dock at the other. With Salyut 6, the Soviets have demonstrated in-flight refueling, and the use of a second vehicle to boost Salyut's orbit, thus extending its lifetime. The Soviets have also docked second crews for visits with the long duration crews, both to bring supplies and to relieve the boredom. Nine of these flights have orbited representatives of the Interkosmos countries (Czechoslovakia, Poland, East Germany, Bulgaria, Hungary, Vietnam, Cuba, Mongolia, and Romania, in that order).

Salyut 6 has not been used for permanent occupancy yet, but that is possible. The Soviets may wait for Salyut 7, though, which is expected to be launched in 1982 and is planned to host a joint Soviet/French crew. Salyut 7 is rumored to be the first of a "modular" space station series which will have several docking ports, to which individual modules will be attached in orbit. In June 1981, the Soviets docked Kosmos 1267 with Salyut 6 and announced that it was a test of this modular concept, although since that time there have been unconfirmed reports in the Western press that Kosmos 1267 is in fact a "space battle station" armed with infrared homing devices. Kosmos 1267 remained docked to Salyut 6 as of February 1982.

Soviet Space Shuttle

Rumors of the imminent appearance of a Soviet version of a reusable space vehicle have been prevalent for at least the past five years. Several Kosmos flights made in the mid- and late-1970's are thought by some Western analysts to have been tests associated with such a vehicle, and there also have been unconfirmed reports that the vehicle has been drop tested from aircraft (similar to the approach and landing tests for the U.S. Shuttle).

While there is no way to definitively determine from unclassified sources whether or not the Soviets are in fact developing such a vehicle, the issue can be discussed in terms of the utility of a reusable vehicle and its likely characteristics. The Soviets have stated their intention to have permanent Earth orbiting space stations, so it would be logical for them to develop a reusable vehicle for ferrying crews back and forth. Since they already have space stations, and seem to have an adequate supply of expendable launch vehicles (ELVs) for orbiting other satellites, it seems unlikely that they would include a cargo bay like that on the U.S. Space Shuttle. An analogy has been drawn by some Western analysts between the rumored Soviet vehicle and the U.S. Dyna-Soar, which was cancelled in 1962 for budget reasons. Essentially, the design is that of a very small reusable vehicle launched by an ELV.

The only clues as to whether such a vehicle is under development are statements by people associated with the Soviet space programs, for example, the cosmonauts. Their most recent statements regarding a Soviet shuttle is that such a system is "not economical at this time". The Soviets have also recently upgraded the Soyuz spacecraft (it is now designated Soyuz-T), possibly indicating that they are not going to introduce an entirely new system in the near future. Thus, one could conclude that it is logical that the Soviets are developing a reusable vehicle, smaller that the U.S. Shuttle, but it is not likely to be introduced for several years.

The Soviet Super-Booster

No discussion of the Soviet manned space program would be complete without mention of the legendary "super-booster" which was rumored to be under development in the 1960's. Often referred to as the "G" vehicle, it was expected to be comparable in thrust to the U.S. Saturn V which sent astronauts to the Moon. The largest existing Soviet booster, the "D" vehicle, is roughly comparable to a Saturn IB, and has never been man-rated.

In the late 1960's, there were

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widespread rumors that the Soviets had attempted three test launches of the G vehicle, all failures. One allegedly killed several leading Soviet spacecraft designers. The lack of a booster of the capability of Saturn V is sometimes credited as the reason the Soviets have never sent men to the Moon, although such a mission could have been accomplished in other ways.

Very little was said about the G vehicle during the 1970's, although rumors of its existence and "imminent" testing have never died. In 1981, the United States published a booklet entitled "Soviet Military Power" which referred to Soviet development of a booster resembling the G vehicle, which served to rekindle the somewhat dormant issue. As with the debate over a Soviet shuttle, there is no way to determine from open sources what the status of the G vehicle is, but the question can be considered from the viewpoint of what utility such a vehicle would have for the Soviets.

A large vehicle would be useful for launching large space stations, for launching other large payloads such as weapon systems, or for manned lunar or planetary flights. The Soviets have indicated that their approach to large space stations will be constructing them from modules in orbit, so a large vehicle would not be necessary for this purpose. Similarly, other large systems could be constructed in orbit, although the ability to launch an entire weapon system with one vehicle would give the Soviets a quick response capability. The Soviets have stated that one reason they are interested in extending the duration of flight for crew members is because they plan to send crews to Mars in the future. Manned planetary flights or flights to the Moon (which still may be a Soviet goal), could be accomplished through earth-orbital assembly of appropriate vehicles, an approach that was considered by the United States in the early 1960's (the lunar orbit rendezvous method was finally chosen instead). A Saturn V sized vehicle would make these tasks easier, however.

In summary, there are several probable programs that could benefit from a G vehicle, but none that apparently require it. The question of whether such a vehicle is under development is more problematical than the shuttle.

PLANETARY PROGRAMS

A great deal of concern has been voiced in the United States recently about the "death" of the U.S. planetary program. Since the beginning of the space age, U.S. probes have visited Mercury, Venus, the Moon, Mars, Jupiter and Saturn, and one is now enroute to Uranus and Neptune. By contrast, the Soviets have sent probes only to Venus, the Moon, and Mars. With Venus and the Moon, they have been very successful. Mars, on the other hand, has eluded their grasp so far.

Soviet probes made the first hard landing and the first soft landing on Venus, and in 1975, Venera 9 and 10 sent back the first photographs of the Venusian surface. Venera 13 and 14

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Soviet Space Activities

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were launched by the Soviets in late 1981, and should reach the planet in March 1982. The Soviets also launched the first probe to reach the Moon, and to send back pictures of the far side. As noted previously, they have also used unmanned probes to return samples of lunar material to Earth, and have sent two Lunokhod roving vehicles to the Moon for on-site observations and chemical analyses. The Soviets have admitted to launching seven probes to Mars (there are other suspected failures in the early 1960's). Several of the probes missed the planet entirely, and those which did reach the planet ceased transmitting at critical times in the mission (one 20 seconds after the probe reached the surface; the other, just before it would have landed).

For the future, it appears that the Soviets are content with doing what they do best – continued studies of Venus. The Moon seems to have lost its appeal (as in the United States), and no Mars attempts have been made since 1973. The next Venus opportunity will be in 1984, and the Soviets are planning a dual mission for that time period. After the two landers are dropped off at Venus, the two fly-by probes will continue on to an intercept with Halley's Comet. The Soviets are establishing an agreement with the European Space Agency and Japan, both of which are also sending probes to the comet, for sharing data from the missions.

MILITARY SPACE ACTIVITIES

The Soviet Union launches satellites at an annual rate several times that of the United States. In 1981, the Soviets made 98 successful launches, compared with 18 for the United States. Although the Soviets do have a more active space program in general, some of the discrepancy in the statistics is due to the number of military launches they make—approximately two-thirds of the launch total in a given year. This is partially caused by the relatively unsophisticated technology of their reconnaissance satellites, which require more frequent replacement than their U.S. counterparts. In addition, most U.S. military communication needs are met by a few satellites in geostationary orbit (GEO), while the Soviets make use of several different types of military communication satellites in non-GEO orbits (they do not use GEO to the extent other nations do—their first GEO satellite was not launched until 1974, 11 years later than the United States).

Military space activities of the two countries are roughly comparable with three major exceptions: the Fractional Orbital Bombardment System (FOBS), antisatellite (ASATs), and radar ocean surveillance satellites. FOBS is essentially an extended range ballistic missile which would permit the Soviets to send warheads to the United States by a trajectory over the South Pole, thus avoiding the Ballistic Missile Early Warning System radars which point to the north.

ASATs are devices which destroy other satellites. The Soviets have made 19 tests of their ground-based ASAT system since 1968, and in 1977, the U.S. Secretary of Defense termed the system operational. The Soviet system involves the launching of a satellite into an orbit close to that of the target satellite. The interceptor maneuvers close to the target and explodes, thus disabling the target with shrapnel. The United States is currently developing an air-launched ASAT system, but it is not expected to be operational until the mid-1980's.

The Soviets have launched radar ocean surveillance satellites since 1967, which provide an advantage over U.S. reconnaissance activities in that the powerful radars permit reconnaissance of U.S. fleet movements even in clouds or darkness. The radars are powered by nuclear reactors, and the unexpected reentry of one of these satellites in 1978 created international concern when radioactive debris was spread over northern Canada. Despite continuing debate at the United Nations over whether reactors should be allowed in space, the Soviets resumed launches of these satellites in 1980.

There have been many rumors that the Soviets are developing directed energy weapons (lasers and particle beams) for use in space either against satellites, or against targets on the planet or in the air. As mentioned previously, there have been reports that Kosmos 1267 is a battle station equipped with infrared homing interceptors. None of these reports has been confirmed.

CONCLUSION

The answer to the question, "will the Soviets confront us with a space spectacular" in the near future depends on the definition of spectacular. It seems very likely that the Soviets will have a permanently occupied space station within the next year or two. Less likely, but not impossible, would be the appearance of a Soviet reusable space vehicle before 1984 or 1985, or the launch of the G vehicle. The Soviets do not appear to be readying anything extraordinary in the planetary arena, although they may gain some international prestige with their Halley's Comet mission.

Militarily, it is possible that a new ASAT system will appear in the next several years, although whether it will be a directed energy weapon or not remains questionable. The Soviets have introduced a treaty at the United Nations to ban weapons from space, but without such a treaty there is nothing to stop either side from developing new non-nucleur systems, and it is unlikely that the treaty will be successfully negotiated soon. (The use of nucleur weapons in space is already prohibited by treaty).

A spectacular Soviet accomplishment in space might serve to push the United States into developing a coherent space policy and specific goals in order to regain leadership in this arena. On the other hand, it may have no impact at all. The accomplishments of the Soviets over the past six years with the space station program are relatively unknown in the United States outside of the space community, even though an event such as refueling Salyut 6 in orbit might have qualified as a highly significant event. These activities have had no discernible impact on U.S. policy. ★

Marcia S. Smith is a specialist in aerospace and energy systems for the Science Policy Research Division of the Congressional Research Service, which provides non-partisan research and analysis to the U.S. Congress. The views expressed here do not necessarily represent those of CRS, any member or committee of Congress or staff thereof.

Future Soviet Space Plans Unveiled

A USSR version of the American Space Shuttle will be flying in five years and a Soviet manned Mars mission may be practical within 10 to 15 years, states Soviet Embassy Attache for Science and Technology, Anatoliy Y. Skripko.

Speaking at a February luncheon of the American Astronautical Society (AAS) in Washington, Skripko told the gathering that a third generation Salyut space station is to appear "in the not too distant future", yielding greater volume and carrying new automatic systems. Such systems will free cosmonaut time to conduct increasing amounts of non-automated space experimentation. The Soviet attache stressed the fact that his country's space engineers are "searching for methods to raise space station efficiency".

Skripko noted the highly successful work of the 27 cosmonauts who have resided in the Salyut-6 orbiting laboratory. Crews have conducted 1,600 experiments, with over 300 materials processing samples obtained using a furnace aboard the high-flying lab. Some 9,000 images of the Earth have also been returned to assist in resource detection and monitoring.

Now in an unmanned mode, Salyut-6 has whirled around the globe since 1977 and "on the whole, could be reused", although the station's electric-generating capacity is dwindling, explained Skripko. In addition, Salyut's windows are covered by dust, hampering Earth and astronomical observations. Space-walking cosmonauts have failed to remove the debris from the windows. Special porthole covers are being designed to be flown on future stations, added Skripko. A decision on whether cosmonauts will revisit Salyut-6 or fly to a yet-to-be-lofted Salyut-7 is expected in 3 to 4 months.

Salyut-6 has demonstrated, stated the attache, that no biological limitations exist to bar long duration space flight by humans. Both the 175 and 185-day marathon flights by cosmonauts, housed in the Salyut-6, show calcium loss levels of about 8%, with 16% calcium loss considered acceptable on Earth. Cosmonauts on these missions returned to Earth with a new composition of red blood cells; the life span of such cells is normally 120 days. Once the cosmonauts readapted to Earth's gravity, the altered cells were replaced by Earth-born cells. "In 10 to 15 years, any person in good health will be able to fly in space. This has been proven by results from our Salyut," said Skripko.

FUTURE DIRECTIONS

As for Soviet space programs in the future, the science representative stated impending Salyut stations will be comprised of many modules: astronomical, technical experiment, and physical and chemical experiment modules. These laboratories can house "large collectives", rather than single crews in near-Earth space, functioning for several years.

The long awaited Soviet space shuttle is not needed at this time, explained Skripko, as expendable spacecraft are now produced in inexpensive quantities. However, a near term goal of Soviet space planners is to provide transportation into orbit at a cost of 25 roubles per kilogram, a translated figure ten times less than projected by using the U.S. space shuttle. Within 5 years a Soviet shuttle may be operating, with "more detailed news" coming in 2 to 3 years, Skripko told the AAS audience.

Soviet scientists have outlined an ambitious space exploration program in several areas: studies of the Sun's relationship with Earth and global climate; continued study of Venus with "aerostats" unleashed in the Venusian atmosphere; comet exploration; and extraterrestrial astronomy utilizing large telescopes. Improved propulsion systems, such as nucleur, ion and plasma engines, are also under study according to Skripko.

The embassy official commented that Salyut stations took the first step toward long-term astronomical observatories. Soviet planners are currently investigating thermal characteristics of future orbiting telescopes, built to carry mirrors of "several meters" diameter in the next decade.

Soviet planetary exploration is to be furthered by unmanned robots, perhaps controlled by artificial intelligence. Such robots, Skripko stated, could pave the way for eventual human expedition to Mars within 10 to 15 years time.

Skripko suggested that, even though the U.S. and the Soviet Union have followed separate space paths, common interests in planetary research, space medicine and biology could be furthered by international cooperation. The Soviet/American political climate, however, makes joint cooperation "difficult, if not impossible," added the Soviet attache. ★

Space Technology

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Arianespace Markets Launch Service

By Jeffrey M. Lenorovitz

PP 87, 90-91, 93, 95.

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Evry, France—Successful entry of Europe's Ariane launch vehicle into worldwide satellite launch services competition has been aided by the private Arianespace organization, which was formed to sell the system to prospective payload customers.

This operation has been credited with much of the market penetration logged by the Europeans during their initial sales promotion efforts. Europe's approach to launch service sales differs from that in the U.S., where the federal government has direct involvement in payload bookings for American launchers. U.S. operations, therefore, are not as marketing-oriented as the European competition.

Technical Gains

Arianespace's sales efforts have been enhanced by technical successes achieved in the final two missions of the four-flight Ariane test program. These launches last June and December helped remove the doubts about Ariane's capability that were raised by the failure of the second test launch in May, 1980.

Completion of the four-flight Ariane test series last Dec. 19, which included the orbiting of the Marecs maritime communications satellite, moved the European launcher system into its operational phase. The program's overall pace is continuing to accelerate. Besides the increased sales efforts, development of the follow-on Ariane 2 and 3 versions is continuing. European approval also is nearing for the Ariane 4 configuration that ultimately will boost the vehicle's lift capacity to 4,000 kg. (8,800 lb.) for geostationary orbit.

The achievements of the last two test launchers, combined with the Arianespace sales progress and the plans for expanding the Ariane family through the fourth launcher derivative, have positioned Ariane as a serious competitor for a range of payload launch customers, including those being sought by the U.S. space shuttle. Arianespace officials said sales of launch slots to the U.S. and other countries have shown the launcher's viability.

"I think we have shown Ariane is not merely a European launcher. We, of course, can rely on certain orders from France and the European Space Agency, but we have demonstrated through our sales that Ariane is viable in other regions," an Arianespace manager said.

Launch vehicle capabilities also are being developed in other countries. These include the Japanese H-1 program, India's expanding family of launchers and a program just beginning in Brazil. The sales potential of these launch vehicles depends on financial resources and technical successes gained in the programs, as well as on the individual nations' policies toward marketing the systems outside their home countries.

The USSR is continuing large-scale launch vehicle efforts, and the People's Republic of China is advancing into launcher development. Neither has emerged as a competitor on a commercial level.

Several U.S. industry officials have stressed the importance of Europe's decision to separate Ariane marketing operations from direct governmental involvement. "What Arianespace has that we in the U.S. do not is the flexibility of a pure marketing force. The organization's goal is to sell the launcher, and it can function differently than if it were directly tied to the government, as is the case in the U.S.," a U.S. space official said.

"Perhaps we can learn something about the way the French, who are the leading force in Arianespace, are handling their marketing."

Many industry officials agree that Europe's Ariane successes in the world market have stemmed from the merging of several key elements:

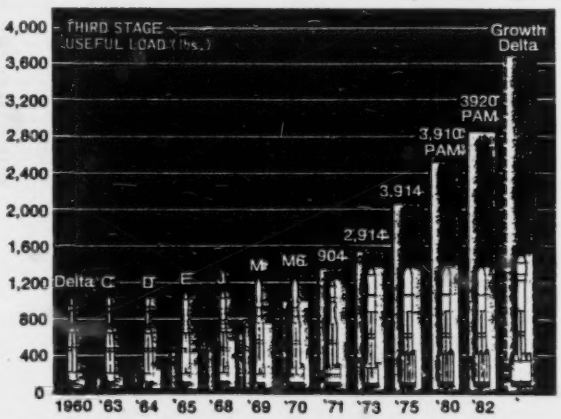
- Continuing improvements in Europe's technology base as well as maturing production techniques.
- Capability of European nations to work efficiently together on multinational programs and to establish coordinated management functions.
- The emergence of European overall marketing capability, particularly in France.

The technology developed in the 1960s was refined in the 1970s as aerospace industries in western Europe evolved expertise in key areas. The pluses and minuses of advanced-technology applications also were considered more carefully during the years of the Ariane's development. For example, it was decided to rely largely on state-of-the-art technology as the basis for Ariane's development rather than to make broad steps into unproved areas, French officials said.

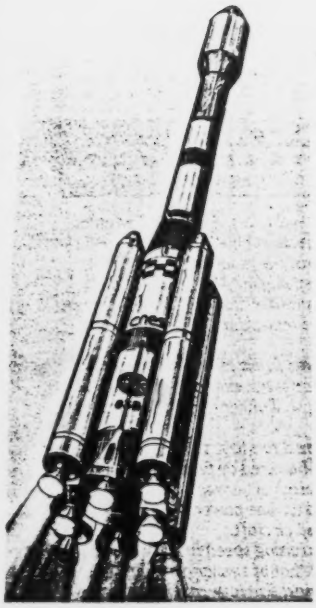
'Route Proved'

"Rather than use technology for technology's sake, we took a more proved route for Ariane," an executive at the French national space agency CNES (Centre National d'Etudes Spatiales) said. "We wanted to develop a reliable and producible system, and decided this was the best approach." As important as technical capability is the improving capacity of European countries to work together on multinational programs.

The improved working relationships



U.S. Delta launcher family, produced by McDonnell Douglas Astronautics Corp., has expanded from its initial configuration in the 1960s to proposed growth versions capable of orbiting payloads that weigh up to 3,000 lb. The vehicle's upgrades are achieved through a variety of methods, including the use of the payload assist module (PAM).



among Europe's aerospace industries is well illustrated by the multinational Airbus Industrie consortium, whose A300/A310 transport aircraft program involves the participation of France, Great Britain, Germany, Spain, Holland and Belgium.

A centralized headquarters is located at Toulouse, France, where the assembly line integrates components produced by the participating countries. The consortium has been able to increase its output significantly.

A production rate of 4.2 aircraft per month is expected to increase to eight per month in 1984. Acceleration of the production rate will allow Airbus to keep pace with the growing sales volume for its twin-engined A300 family.

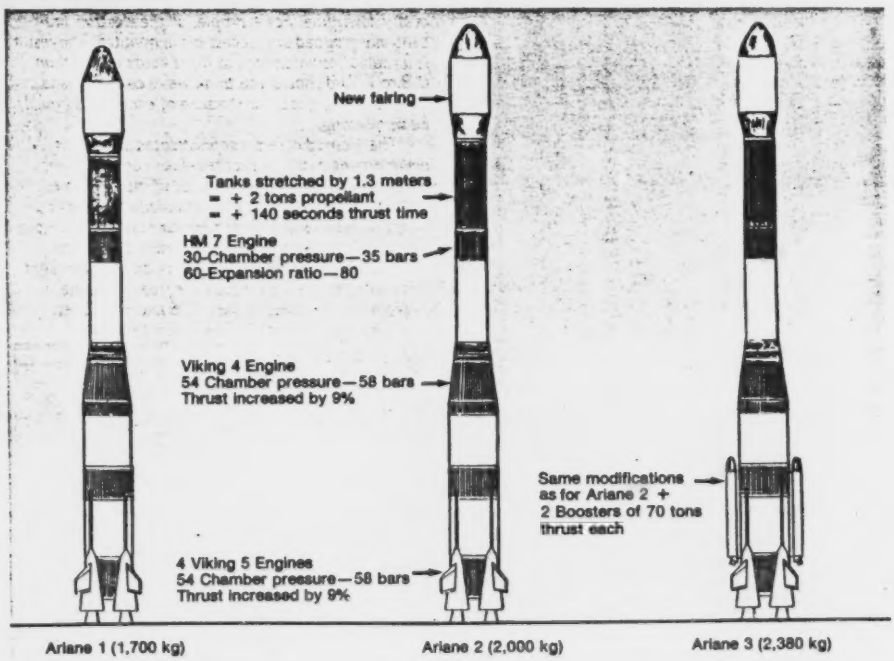
"Although the Ariane launcher and A300 transport are not exactly the same type of product, they both represent current aerospace technology and are examples of successes we in Europe are realizing as the result of working together," a Germany industry executive said.

Another element in Europe's commercial aerospace advances is the maturing of marketing techniques among European sales forces. Some of the earlier shortcomings in sales approaches to non-European nations have been resolved, and such innovations as the formation of the Arianespace organization have materialized.

Arianespace was formed in 1980 to handle the industrial management of Ariane, plus the marketing of launch services, control of launch operations at the Guiana Space Center and financing of launcher production.

It is a private company with support from the governments of participating nations and the backing of several European banks. Shareholders include government agencies such as France's CNES; companies involved in Ariane pro-

Configurations of three international expendable launcher systems are shown. The European multinational Ariane program has evolved three specific versions (below) and the development of a fourth is nearing approval by the participating nations (left). The basic Ariane 1 has been used in the initial launch series and is capable of placing 1,700-kg. (3,740-lb.) payloads in geostationary transfer orbits, while the follow-on Ariane 2 and 3 derivatives increase the capability to 2,000 kg. (4,409 lb.) and 2,380 kg. (5,247 lb.), respectively. The proposed Ariane 4 would be capable of placing 4,000-kg. (8,800-lb.) payloads into geostationary orbit in the heavyweight version equipped with four liquid strap-on boosters.



duction such as France's Aerospatiale, West Germany's Dornier, Messerschmitt-Boelkow-Blohm and ERNO, and Spain's CASA, and banking organizations ranging from the French Credit Lyonnais to Germany's Dresdnerbank and Italy's Istituto Bancario San Paolo di Torino.

Total shares are distributed among sources in the 11 involved countries, with France holding the largest share at 59.25%. The other share distributions include 19.6% in Germany, 4.4% in Belgium, 3.6% among Italian organizations, 2.7% in Switzerland, 2.5% in Spain, 2.4% each in Great Britain and Sweden, 2.2% with Dutch shareholders, 0.25% in Ireland and 0.70% among Danish shareholders.

Although Arianespace was established separately from the French government, it is able to derive key benefits from its close ties to French national research and technology agencies and with its aerospace industry. This relationship is evidenced by the location of Arianespace at the CNES facility here at Evry outside Paris.

"The way the French national space agency CNES nurtured Arianespace has provided a strong foundation for the marketing organization. It is able to transition promising personnel to the Arianespace marketing group and provide invaluable support, and in this manner strengthen the overall effectiveness of the marketing operation," one European-based U.S. industry representative said.

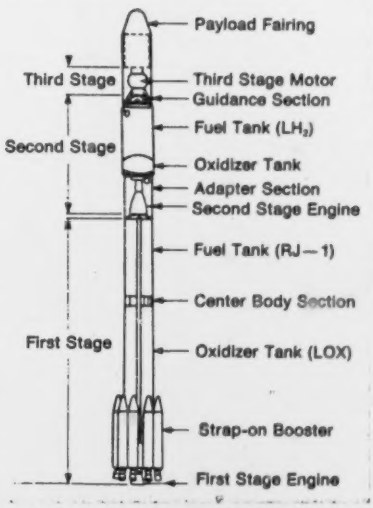
As Arianespace seeks to increase its sales in the world market, launcher capabilities also are emerging from several locations outside Europe and the U.S. India is one such country that is working to develop its launch vehicle program as well as the capability to build spacecraft for its telecommunications and other needs. India's technological advances have been derived in part from its close ties with Europe and the U.S.

India has been able to train its personnel in the U.S., Europe and elsewhere, and it has had direct infusions of technology through these worldwide connections. Approximately 50 Indian engineers have been involved in Ariane work at CNES and at France's propulsion company SEP (Societe Europeenne de Propulsion), and France helped India develop its SLV-3 launcher.

India's Apple communications satellite, which was built with technological help from other countries, was orbited on the successful third Ariane test flight in June, 1981, and it is continuing its operations despite some initial on-board problems (AWAST Sept. 14, 1981, p. 19).

India plans to improve the capability of its own launch vehicle from 50 kg. (110 lb.) to about 150 kg. (330 lb.) during the next few years. Beyond this, the country's space agency ISRO (Indian Space Research Organization) is examining a significantly larger vehicle that could orbit 600-700-kg. (1,320-1,540-lb.) payloads. The larger vehicle could be a four-stage solid/liquid-fueled launcher.

Japan is increasing its launcher family. The next step is represented by the National Space Development Agency's H-1 vehicle, capable of placing 550-kg. (1,210-lb.) payloads in geostationary orbit. Flight tests of a two-stage version are scheduled in 1986, and the three-stage configuration will be tested in 1987.



Japan is developing a new launcher that is expected to be capable of carrying 550 kg. (1,210 lb.) payloads into geostationary orbit. The three-stage H-1 launcher is under development by the National Space Development Agency (NASDA), and it is expected to meet the need for launching of heavier applications satellites for Japanese users in the late 1980s and through the 1990s.

The H-1 is being evolved from technology established through Japan's N series of rockets, which utilize some hardware and technology from the National Aeronautics and Space Administration's Thor-Delta launcher family.

As development work continues on the first H-1 versions, Japan also is evaluating an upgraded H-1 that could place payloads of 800 kg. (1,760 lb.) to one metric ton in geostationary orbit.

If Japan wants to market the H-1 vehicles for commercial launching services, questions concerning the use of the U.S. technology incorporated in them for commercial ventures would have to be sorted out, a U.S. official said. The official noted, however, that Japan's ability to become a major commercial launch services competitor is limited by several inherent factors. Its launch windows are restricted to two periods per year because of clearances that must be arranged with the Japanese fishing industry in the waters on the country's launcher ranges.

"It is only speculation, but if Japan wants to enter the commercial space market, I think it would be more likely for the country to offer such services as earth-monitoring data from the satellites it develops through its industry and then launches on its own vehicles," the U.S. official said. "This way it could offer marketable services in imaging, plus other earth resources capabilities and satellite transponder capacity, rather than try to work on commercial launcher services separately."

Any competitive threat that may have been posed by the privately funded German Orbital Transport- und Raketen-Aktiengesellschaft (Otrag) seems to have ended for the time being with the company's termination of launch operations in Libya. Otrag had said it would test a two-stage rocket launcher from its Libyan range that could be used to place satellites into geostationary or

Sales Goals Projected for Ariane

Paris—Arianespace, the marketing organization for Europe's Ariane launcher, has set an objective of capturing orders for 25-30% of the approximately 200 satellites expected to be orbited during 1983-90.

Firm contracts already booked for the Ariane have provided for the production of 19 vehicles, and additional commitments are expected.

The 19-launcher total covers the four development vehicles that have been tested during the Ariane's development phase, six additional Arianes for the upcoming European Space Agency promotional series and nine others that are to be launched under Arianespace authority.

According to Arianespace estimates, the organization's order book is worth 2.4 billion francs (approximately $428.5 million), of which 40% originated outside the European Economic Community. In 1984, when Arianespace takes over all Ariane launch activities at the conclusion of the ESA series, the group's annual sales are targeted to be 1.6 billion francs (approximately $285.7 million).

Ariane 4 in French 1982 Budget

Paris—The French government's 1982 budget includes funding for several key elements of the country's near- and long-term space programs. These involve financial support for developing the follow-on Ariane 4 launcher configuration, the construction of a second Spot earth-imaging satellite, establishment of the Spot image marketing support organization and participation in several European Space Agency programs.

Finances for the Ariane 4 will allow development of this latest version to begin this year. Some of the system's contracts are expected to be issued to industry this month. The Ariane 4 will be fitted with a variety of solid or liquid strap-on boosters—or combinations of the two—to produce various launch capabilities up to a heavy-lift version with payload capacity of about 9,460 lb. (AWAST Oct. 12, 1981, p. 87).

The Ariane 4 project is expected to be handled within the framework of ESA, and final ESA approval is under way as the agency's member nations make formal commitments for their shares of program participation.

Other elements of the 1982 French budget provide funding for a second Spot earth-imaging satellite and support for the formation of the Spot image marketing organization.

Provision of the second Spot spacecraft will provide the extension of Spot imaging services for users through the 1980s, according to program officials. The first Spot satellite is under development, and it is targeted for launch on an Ariane 2 launcher in 1984. As with most spacecraft of this type, the Spot spacecraft payload has a design lifetime of two years.

France's 1982 budget provisions also cover the country's participation in several new ESA programs, including the ERS-1 earth resources satellite, a follow-on development program for the ESA Spacelab orbital laboratory facility and a microgravity program.

The ERS-1 is an ocean-monitoring satellite that will carry a synthetic aperture radar, microwave scatterometer and radar altimeter. This satellite is to be based on the same multimission platform bus design used in the French Spot program. Launch for ERS-1 is targeted for 1987.

ESA's Spacelab follow-on development program will provide for continuing development of the orbital facility to be carried in the payload bay of the U. S. space shuttle orbiter (AWAST Dec. 21, 1981, p. 52). The initial work will concentrate on improving the Spacelab design to increase mission duration, and this will be followed by studies of developing free-flying payload units that could be released from the shuttle orbiter for retrieval a minimum of 30 days later. The third follow-on work phase involves studies to prepare Europe for future decisions on its space transportation system, including the possibilities of manned orbital station development with the U. S., or a European development of unmanned platforms based on the Spacelab retrievable carrier.

low-earth orbits. Otrag had offered itself as a private commercial alternative to Ariane and other launchers amid claims by aerospace officials that Otrag was a tax shelter with no real plans to launch satellites (AWAST Dec. 14, 1981, p. 22).

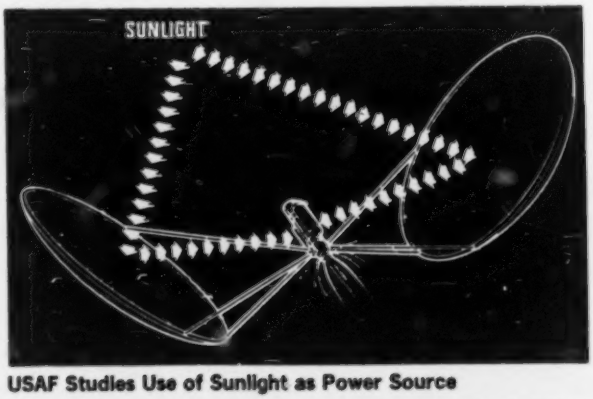
Another private group—this one based in the U. S.—says it is continuing with plans to develop a non-government-sponsored launcher—the Percheron—despite the failure it experienced during ground testing last year (AWAST Aug. 10, 1981, p. 26). Two private companies, Space Services, Inc., of Houston, Tex., and GHC, Inc., of Sunnyvale, Calif., supported development of the Percheron system to compete for commercial payloads with the U. S. Delta and European Ariane.

Brazil plans to develop a satellite and telecommunications network and is seeking bids from worldwide industry sources for such a network that would include the transfer of certain high technology to Brazilian industry. The two competing finalist teams for the Brazilian contract are Canada's Spar with Hughes Aircraft, against a three-way team of France's Aerospatiale, Ford Aerospace and Communications Corp. of the U. S., and Thomson CSF of France. As part of the Aerospatiale/Ford/Thomson CSF bid, France has authorized a package offer for Brazil that would include financial support for the satellites, plus Arianespace-backed launches on a double-payload configuration of the Ariane, and the supply of ground communications stations.

The launcher capabilities that exist in the Soviet Union and that are developing in China are considered to be competitive only on a political level, since the two countries' policies keep much of their programs secret. The Soviet Union, for example, has launched some satellites for India and participated with France in cooperative spacecraft projects that included launches on Soviet vehicles, but this is significantly different from commercialized handling of launcher capacity.

China is in the early development of its launchers. Chinese officials visiting western Europe in 1981 indicated the country may be interested in expanding its contacts with other nations' aerospace industries and in the future could discuss the launch of payloads for certain countries. According to European aerospace experts, the Chinese Long March 3 launcher vehicle is similar in concept to the Ariane.

The primary competitor for Europe's Ariane is the U. S. Delta launcher, which



USAF Studies Use of Sunlight as Power Source

Use of sunlight as the power source for an advanced space propulsion system is the goal of the solar rocket propulsion program at the USAF Rocket Propulsion Laboratory at Edwards AFB, Calif. The concept features lightweight mirrors to focus solar energy into the rocket chamber where propellant is heated to temperatures approximately 2,300K, then exhausted through a conventional rocket nozzle. Missions envisioned for the solar rocket would be those requiring long duration, low thrust (1 lb. or less) applications.

has one of the largest booking levels in the program's 21-year history. The initial version was flown in 1960, and future growth configurations have been studied by its manufacturer, McDonnell Douglas Astronautics Corp., for Delta vehicles that could boost transfer orbit throw-weight capability up to 3,000 lb.

Program officials said Delta has had an overall reliability of about 93% in total firings since 1960. Substantial reliability improvements that were implemented after a Delta launch failure in 1974 have added to the launcher's success rate, with about a 96% reliability rate attained during the launches made during the past seven years.

"The Delta has a reliability record that will be difficult to equal by other expendable launchers," a U.S. program official said.

"As far as the marketing aspects are concerned, the program sees a continuing need among the payload community, and the U.S. has continued to support the Delta users even though our marketing may not have the same commercialized structure as the more recent European approach with Arianespace."

One potential area of new U.S. launcher competition that will be monitored closely by European Ariane participants is the possible development of new U.S. expendable vehicles and shuttle-derived cargo vehicles. A study is under way by Boeing for a new unmanned vehicle based on the recoverable space shuttle solid rocket booster (AWAST Dec. 7, 1981, p. 22). This effort is among several U.S. industry examinations of systems that could be used for a "mixed fleet" launcher concept. □

Ariane Contractors

Evry, France—Arianespace is working with seven contractors in the manufacture of Ariane launchers. These are:

- **France's Aerospatiale**—Responsibility for the first and third stages and the launch vehicle's overall design.
- **Societe Europeenne de Propulsion of France**—This company has the contract for propulsion systems for the vehicle's three stages.
- **Germany's ERNO**—Development and production of the second stage.
- **Matra of France**—Responsible for Ariane's equipment bay.
- **Contraves of Switzerland**—Production of the payload fairing.
- **France's Air Liquide**—Produces the third-stage tank.
- **Italy's Difesa e Spazio**—Responsible for the additional solid boosters that will be used in the growth versions of Ariane.

These companies subcontract a sizable portion of their production work to various firms in the 11 countries participating in the Ariane program.

IV. MILITARIZATION OF SPACE

National Security

Address to the Nation. March 23, 1983

My fellow Americans, thank you for sharing your time with me tonight.

The subject I want to discuss with you, peace and national security, is both timely and important. Timely, because I've reached a decision which offers a new hope for our children in the 21st century, a decision I'll tell you about in a few minutes. And important because there's a very big decision that you must make for yourselves. This subject involves the most basic duty that any President and any people share, the duty to protect and strengthen the peace.

At the beginning of this year, I submitted to the Congress a defense budget which reflects my best judgment of the best understanding of the experts and specialists who advise me about what we and our allies must do to protect our people in the years ahead. That budget is much more than a long list of numbers, for behind all the numbers lies America's ability to prevent the greatest of human tragedies and preserve our free way of life in a sometimes dangerous world. It is part of a careful, long-term plan to make America strong again after too many years of neglect and mistakes.

Our efforts to rebuild America's defenses and strengthen the peace began 2 years ago when we requested a major increase in the defense program. Since then, the amount of those increases we first proposed has been reduced by half, through improvements in management and procurement and other savings.

The budget request that is now before the Congress has been trimmed to the limits of safety. Further deep cuts cannot be made without seriously endangering the security of the Nation. The choice is up to the men and women you've elected to the Congress, and that means the choice is up to you.

Tonight, I want to explain to you what this defense debate is all about and why I'm convinced that the budget now before the Congress is necessary, responsible, and de-

Reproduced from Reagan, Ronald. National security address to the Nation, March 23, 1983. Weekly compilation of Presidential documents, v. 19, Mar. 28, 1983: 442-448.

serving of your support. And I want to offer hope for the future.

But first, let me say what the defense debate is not about. It is not about spending arithmetic. I know that in the last few weeks you've been bombarded with numbers and percentages. Some say we need only a 5-percent increase in defense spending. The so-called alternate budget backed by liberals in the House of Representatives would lower the figure to 2 to 3 percent, cutting our defense spending by $163 billion over the next 5 years. The trouble with all these numbers is that they tell us little about the kind of defense program America needs or the benefits and security and freedom that our defense effort buys for us.

What seems to have been lost in all this debate is the simple truth of how a defense budget is arrived at. It isn't done by deciding to spend a certain number of dollars. Those loud voices that are occasionally heard charging that the Government is trying to solve a security problem by throwing money at it are nothing more than noise based on ignorance. We start by considering what must be done to maintain peace and review all the possible threats against our security. Then a strategy for strengthening peace and defending against those threats must be agreed upon. And, finally, our defense establishment must be evaluated to see what is necessary to protect against any or all of the potential threats. The cost of achieving these ends is totaled up, and the result is the budget for national defense.

There is no logical way that you can say, let's spend x billion dollars less. You can only say, which part of our defense measures do we believe we can do without and still have security against all contingencies? Anyone in the Congress who advocates a percentage or a specific dollar cut in defense spending should be made to say what part of our defenses he would eliminate, and he should be candid enough to acknowledge that his cuts mean cutting our commitments to allies or inviting greater risk or both.

The defense policy of the United States is based on a simple premise: The United States does not start fights. We will never be an aggressor. We maintain our strength in order to deter and defend against aggression—to preserve freedom and peace.

Since the dawn of the atomic age, we've sought to reduce the risk of war by maintaining a strong deterrent and by seeking genuine arms control. "Deterrence" means simply this: making sure any adversary who thinks about attacking the United States, or our allies, or our vital interests, concludes that the risks to him outweigh any potential gains. Once he understands that, he won't attack. We maintain the peace through our strength, weakness only invites aggression.

This strategy of deterrence has not changed. It still works. But what it takes to maintain deterrence has changed. It took one kind of military force to deter an attack when we had far more nuclear weapons than any other power; it takes another kind now that the Soviets, for example, have enough accurate and powerful nuclear weapons to destroy virtually all of our missiles on the ground. Now, this is not to say that the Soviet Union is planning to make war on us. Nor do I believe a war is inevitable—quite the contrary. But what must be recognized is that our security is based on being prepared to meet all threats.

There was a time when we depended on coastal forts and artillery batteries, because, with the weaponry of that day, any attack would have had to come by sea. Well, this is a different world, and our defenses must be based on recognition and awareness of the weaponry possessed by other nations in the nuclear age.

We can't afford to believe that we will never be threatened. There have been two world wars in my lifetime. We didn't start them and, indeed, did everything we could to avoid being drawn into them. But we were ill-prepared for both. Had we been better prepared, peace might have been preserved.

For 20 years the Soviet Union has been accumulating enormous military might. They didn't stop when their forces exceeded all requirements of a legitimate defensive capability. And they haven't stopped now. During the past decade and a half, the Soviets have built up a massive arsenal of new strategic nuclear weapons—weapons that can strike directly at the United States.

As an example, the United States introduced its last new intercontinental ballistic missile, the Minute Man III, in 1969, and we're now dismantling our even older Titan missiles. But what has the Soviet Union done in these intervening years? Well, since 1969 the Soviet Union has built five new classes of ICBM's, and upgraded these eight times. As a result, their missiles are much more powerful and accurate than they were several years ago, and they continue to develop more, while ours are increasingly obsolete.

The same thing has happened in other areas. Over the same period, the Soviet Union built 4 new classes of submarine-launched ballistic missiles and over 60 new missile submarines. We built 2 new types of submarine missiles and actually withdrew 10 submarines from strategic missions. The Soviet Union built over 200 new Backfire bombers, and their brand new Blackjack bomber is now under development. We haven't built a new long-range bomber since our B–52's were deployed about a quarter of a century ago, and we've already retired several hundred of those because of old age. Indeed, despite what many people think, our strategic forces only cost about 15 percent of the defense budget.

Another example of what's happened: In 1978 the Soviets had 600 intermediate-range nuclear missiles based on land and were beginning to add the SS–20—a new, highly accurate, mobile missile with 3 warheads. We had none. Since then the Soviets have strengthened their lead. By the end of 1979, when Soviet leader Brezhnev declared "a balance now exists," the Soviets had over 800 warheads. We still had none. A year ago this month, Mr. Brezhnev pledged a moratorium, or freeze, on SS–20 deployment. But by last August, their 800 warheads had become more than 1,200. We still had none. Some freeze. At this time Soviet Defense Minister Ustinov announced "approximate parity of forces continues to exist." But the Soviets are still adding an average of 3 new warheads a week, and now have 1,300. These warheads can reach their targets in a matter of a few minutes. We still have none. So far, it seems that the Soviet definition of parity is a box score of 1,300 to nothing, in their favor.

So, together with our NATO allies, we decided in 1979 to deploy new weapons, beginning this year, as a deterrent to their SS–20's and as an incentive to the Soviet Union to meet us in serious arms control negotiations. We will begin that deployment late this year. At the same time, however, we're willing to cancel our program if the Soviets will dismantle theirs. This is what we've called a zero-zero plan. The Soviets are now at the negotiating table—and I think it's fair to say that without our planned deployments, they wouldn't be there.

Now, let's consider conventional forces. Since 1974 the United States has produced 3,050 tactical combat aircraft. By contrast, the Soviet Union has produced twice as many. When we look at attack submarines, the United States has produced 27 while the Soviet Union has produced 61. For armored vehicles, including tanks, we have produced 11,200. The Soviet Union has produced 54,000—nearly 5 to 1 in their favor. Finally, with artillery, we've produced 950 artillery and rocket launchers while the Soviets have produced more than 13,000—a staggering 14-to-1 ratio.

There was a time when we were able to offset superior Soviet numbers with higher quality, but today they are building weapons as sophisticated and modern as our own.

As the Soviets have increased their military power, they've been emboldened to extend that power. They're spreading their military influence in ways that can directly challenge our vital interests and those of our allies.

The following aerial photographs, most of them secret until now, illustrate this point in a crucial area very close to home: Central America and the Caribbean Basin. They're not dramatic photographs. But I think they help give you a better understanding of what I'm talking about.

This Soviet intelligence collection facility, less than a hundred miles from our coast, is the largest of its kind in the world. The acres and acres of antennae fields and intelligence monitors are targeted on key U.S. military installations and sensitive activities. The installation in Lourdes, Cuba, is manned by 1,500 Soviet technicians. And

the satellite ground station allows instant communications with Moscow. This 28-square-mile facility has grown by more than 60 percent in size and capability during the past decade.

In western Cuba, we see this military airfield and it complement of modern, Soviet-built Mig-23 aircraft. The Soviet Union uses this Cuban airfield for its own long-range reconnaissance missions. And earlier this month, two modern Soviet antisubmarine warfare aircraft began operating from it. During the past 2 years, the level of Soviet arms exports to Cuba can only be compared to the levels reached during the Cuban missile crisis 20 years ago.

This third photo, which is the only one in this series that has been previously made public, shows Soviet military hardware that has made its way to Central America. This airfield with its MI–8 helicopters, anti-aircraft guns, and protected fighter sites is one of a number of military facilities in Nicaragua which has received Soviet equipment funneled through Cuba, and reflects the massive military buildup going on in that country.

On the small island of Grenada, at the southern end of the Caribbean chain, the Cubans, with Soviet financing and backing, are in the process of building an airfield with a 10,000-foot runway. Grenada doesn't even have an air force. Who is it intended for? The Caribbean is a very important passageway for our international commerce and military lines of communication. More than half of all American oil imports now pass through the Caribbean. The rapid buildup of Grenada's military potential is unrelated to any conceivable threat to this island country of under 110,000 people and totally at odds with the pattern of other eastern Caribbean States, most of which are unarmed.

The Soviet-Cuban militarization of Grenada, in short, can only be seen as power projection into the region. And it is in this important economic and strategic area that we're trying to help the Governments of El Salvador, Costa Rica, Honduras, and others in their struggles for democracy against guerrillas supported through Cuba and Nicaragua.

These pictures only tell a small part of the story. I wish I could show you more without compromising our most sensitive intelligence sources and methods. But the Soviet Union is also supporting Cuban military forces in Angola and Ethiopia. They have bases in Ethiopia and South Yemen, near the Persian Gulf oil fields. They've taken over the port that we built at Cam Ranh Bay in Vietnam. And now for the first time in history, the Soviet Navy is a force to be reckoned with in the South Pacific.

Some people may still ask: Would the Soviets ever use their formidable military power? Well, again, can we afford to believe they won't? There is Afghanistan. And in Poland, the Soviets denied the will of the people and in so doing demonstrated to the world how their military power could also be used to intimidate.

The final fact is that the Soviet Union is acquiring what can only be considered an offensive military force. They have continued to build far more intercontinental ballistic missiles than they could possibly need simply to deter an attack. Their conventional forces are trained and equipped not so much to defend against an attack as they are to permit sudden, surprise offensives of their own.

Our NATO allies have assumed a great defense burden, including the military draft in most countries. We're working with them and our other friends around the world to do more. Our defensive strategy means we need military forces that can move very quickly, forces that are trained and ready to respond to any emergency.

Every item in our defense program—our ships, our tanks, our planes, our funds for training and spare parts—is intended for one all-important purpose: to keep the peace. Unfortunately, a decade of neglecting our military forces had called into question our ability to do that.

When I took office in January 1981, I was appalled by what I found: American planes that couldn't fly and American ships that couldn't sail for lack of spare parts and trained personnel and insufficient fuel and ammunition for essential training. The inevitable result of all this was poor morale in our Armed Forces, difficulty in recruiting the brightest young Americans to wear the uniform, and difficulty in convincing our

most experienced military personnel to stay on.

There was a real question then about how well we could meet a crisis. And it was obvious that we had to begin a major modernization program to ensure we could deter aggression and preserve the peace in the years ahead.

We had to move immediately to improve the basic readiness and staying power of our conventional forces, so they could meet—and therefore help deter—a crisis. We had to make up for lost years of investment by moving forward with a long-term plan to prepare our forces to counter the military capabilities our adversaries were developing for the future.

I know that all of you want peace, and so do I. I know too that many of you seriously believe that a nuclear freeze would further the cause of peace. But a freeze now would make us less, not more, secure and would raise, not reduce, the risks of war. It would be largely unverifiable and would seriously undercut our negotiations on arms reduction. It would reward the Soviets for their massive military buildup while preventing us from modernizing our aging and increasingly vulnerable forces. With their present margin of superiority, why should they agree to arms reductions knowing that we were prohibited from catching up?

Believe me, it wasn't pleasant for someone who had come to Washington determined to reduce government spending, but we had to move forward with the task of repairing our defenses or we would lose our ability to deter conflict now and in the future. We had to demonstrate to any adversary that aggression could not succeed, and that the only real solution was substantial, equitable, and effectively verifiable arms reduction—the kind we're working for right now in Geneva.

Thanks to your strong support, and bipartisan support from the Congress, we began to turn things around. Already, we're seeing some very encouraging results. Quality recruitment and retention are up dramatically—more high school graduates are choosing military careers, and more experienced career personnel are choosing to stay. Our men and women in uniform at last are getting the tools and training they need to do their jobs.

Ask around today, especially among our young people, and I think you will find a whole new attitude toward serving their country. This reflects more than just better pay, equipment, and leadership. You the American people have sent a signal to these young people that it is once again an honor to wear the uniform. That's not something you measure in a budget, but it's a very real part of our nation's strength.

It'll take us longer to build the kind of equipment we need to keep peace in the future, but we've made a good start.

We haven't built a new long-range bomber for 21 years. Now we're building the B–1. We hadn't launched one new strategic submarine for 17 years. Now we're building one Trident submarine a year. Our land-based missiles are increasingly threatened by the many huge, new Soviet ICBM's. We're determining how to solve that problem. At the same time, we're working in the START and INF negotiations with the goal of achieving deep reductions in the strategic and intermediate nuclear arsenals of both sides.

We have also begun the long-needed modernization of our conventional forces. The Army is getting its first new tank in 20 years. The Air Force is modernizing. We're rebuilding our Navy, which shrank from about a thousand ships in the late 1960's to 453 during the 1970's. Our nation needs a superior navy to support our military forces and vital interests overseas. We're now on the road to achieving a 600-ship navy and increasing the amphibious capabilities of our marines, who are now serving the cause of peace in Lebanon. And we're building a real capability to assist our friends in the vitally important Indian Ocean and Persian Gulf region.

This adds up to a major effort, and it isn't cheap. It comes at a time when there are many other pressures on our budget and when the American people have already had to make major sacrifices during the recession. But we must not be misled by those who would make defense once again the scapegoat of the Federal budget.

The fact is that in the past few decades we have seen a dramatic shift in how we spend the taxpayer's dollar. Back in 1955, payments to individuals took up only about

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20 percent of the Federal budget. For nearly three decades, these payments steadily increased and, this year, will account for 49 percent of the budget. By contrast, in 1955 defense took up more than half of the Federal budget. By 1980 this spending had fallen to a low of 23 percent. Even with the increase that I am requesting this year, defense will still amount to only 28 percent of the budget.

The calls for cutting back the defense budget come in nice, simple arithmetic. They're the same kind of talk that led the democracies to neglect their defenses in the 1930's and invited the tragedy of World War II. We must not let that grim chapter of history repeat itself through apathy or neglect.

This is why I'm speaking to you tonight—to urge you to tell your Senators and Congressmen that you know we must continue to restore our military strength. If we stop in midstream, we will send a signal of decline, of lessened will, to friends and adversaries alike. Free people must voluntarily, through open debate and democratic means, meet the challenge that totalitarians pose by compulsion. It's up to us, in our time, to choose and choose wisely between the hard but necessary task of preserving peace and freedom and the temptation to ignore our duty and blindly hope for the best while the enemies of freedom grow stronger day by day.

The solution is well within our grasp. But to reach it, there is simply no alternative but to continue this year, in this budget, to provide the resources we need to preserve the peace and guarantee our freedom.

Now, thus far tonight I've shared with you my thoughts on the problems of national security we must face together. My predecessors in the Oval Office have appeared before you on other occasions to describe the threat posed by Soviet power and have proposed steps to address that threat. But since the advent of nuclear weapons, those steps have been increasingly directed toward deterrence of aggression through the promise of retaliation.

This approach to stability through offensive threat has worked. We and our allies have succeeded in preventing nuclear war for more than three decades. In recent months, however, my advisers, including in particular the Joint Chiefs of Staff, have underscored the necessity to break out of a future that relies solely on offensive retaliation for our security.

Over the course of these discussions, I've become more and more deeply convinced that the human spirit must be capable of rising above dealing with other nations and human beings by threatening their existence. Feeling this way, I believe we must thoroughly examine every opportunity for reducing tensions and for introducing greater stability into the strategic calculus on both sides.

One of the most important contributions we can make is, of course, to lower the level of all arms, and particularly nuclear arms. We're engaged right now in several negotiations with the Soviet Union to bring about a mutual reduction of weapons. I will report to you a week from tomorrow my thoughts on that score. But let me just say, I'm totally committed to this course.

If the Soviet Union will join with us in our effort to achieve major arms reduction, we will have succeeded in stabilizing the nuclear balance. Nevertheless, it will still be necessary to rely on the specter of retaliation, on mutual threat. And that's a sad commentary on the human condition. Wouldn't it be better to save lives than to avenge them? Are we not capable of demonstrating our peaceful intentions by applying all our abilities and our ingenuity to achieving a truly lasting stability? I think we are. Indeed, we must.

After careful consultation with my advisers, including the Joint Chiefs of Staff, I believe there is a way. Let me share with you a vision of the future which offers hope. It is that we embark on a program to counter the awesome Soviet missile threat with measures that are defensive. Let us turn to the very strengths in technology that spawned our great industrial base and that have given us the quality of life we enjoy today.

What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack, that we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies?

I know this is a formidable, technical task, one that may not be accomplished before the end of this century. Yet, current technology has attained a level of sophistication where it's reasonable for us to begin this effort. It will take years, probably decades of effort on many fronts. There will be failures and setbacks, just as there will be successes and breakthroughs. And as we proceed, we must remain constant in preserving the nuclear deterrent and maintaining a solid capability for flexible response. But isn't it worth every investment necessary to free the world from the threat of nuclear war? We know it is.

In the meantime, we will continue to pursue real reductions in nuclear arms, negotiating from a position of strength that can be ensured only by modernizing our strategic forces. At the same time, we must take steps to reduce the risk of a conventional military conflict escalating to nuclear war by improving our non-nuclear capabilities.

America does possess—now—the technologies to attain very significant improvements in the effectiveness of our conventional, non-nuclear forces. Proceeding boldly with these new technologies, we can significantly reduce any incentive that the Soviet Union may have to threaten attack against the United States or its allies.

As we pursue our goal of defensive technologies, we recognize that our allies rely upon our strategic offensive power to deter attacks against them. Their vital interests and ours are inextricably linked. Their safety and ours are one. And no change in technology can or will alter that reality. We must and shall continue to honor our commitments.

I clearly recognize that defensive systems have limitations and raise certain problems and ambiguities. If paired with offensive systems, they can be viewed as fostering an aggressive policy, and no one wants that. But with these considerations firmly in mind, I call upon the scientific community in our country, those who gave us nuclear weapons, to turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impotent and obsolete.

Tonight, consistent with our obligations of the ABM treaty and recognizing the need for closer consultation with our allies, I'm taking an important first step. I am directing a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles. This could pave the way for arms control measures to eliminate the weapons themselves. We seek neither military superiority nor political advantage. Our only purpose—one all people share—is to search for ways to reduce the danger of nuclear war.

My fellow Americans, tonight we're launching an effort which holds the promise of changing the course of human history. There will be risks, and results take time. But I believe we can do it. As we cross this threshold, I ask for your prayers and your support.

Thank you, good night, and God bless you.

Note: The President spoke at 8:02 p.m. from the Oval Office at the White House. The address was broadcast live on nationwide radio and television.

Following his remarks, the President met in the White House with a number of administration officials, including members of the Cabinet, the White House staff, and the Joint Chiefs of Staff, and former officials of past administrations to discuss the address.

98th Congress, 2d Session - - - - - - - - - - House Document 98-197

U.S. POLICY ON ASAT ARMS CONTROL

COMMUNICATION

FROM

THE PRESIDENT OF THE UNITED STATES

TRANSMITTING

A REPORT ON HIS ADMINISTRATION'S POLICY ON ARMS CONTROL FOR ANTISATELLITE SYSTEMS AS REQUIRED IN THE CONFERENCE REPORT FOR THE DEPARTMENT OF DEFENSE APPROPRIATIONS ACT FOR FISCAL YEAR 1984

APRIL 3, 1984.—Referred to the Committee on Appropriations and ordered to be printed

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U.S. GOVERNMENT PRINTING OFFICE

31-011 O WASHINGTON : 1984

THE WHITE HOUSE,
Washington, March 31, 1984.

Hon. THOMAS P. O'NEILL, JR.,
Speaker of the House of Representatives,
Washington, D.C.

DEAR MR. SPEAKER: I am pleased to transmit this report on my Administration's policy on arms control for antisatellite systems as required in the Conference Report for the Department of Defense Appropriations Act for Fiscal Year 1984.

The United States is committed to the exploration and use of space by all nations for peaceful purposes and for the benefit of mankind. Among the activities conducted by the United States in space is the pursuit of fundamental national security objectives. Arms control arrangements for space would serve these objectives if they contributed to our overall deterrence posture and reduce the risk of conflict.

With this in mind, I announced on July 4, 1982, the basic posture of this Administration which I now reaffirm:

"The United States will continue to study space arms control options. The United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapons systems, should those measures be compatible with United States national security."

Guided by these criteria, the United States has been studying a range of possible options for space arms control, with a view to possible negotiations with the Soviet Union and other nations, if such negotiations would serve U.S. interests. Within the U.S. Government, this work is being conducted by an Interdepartmental Group chaired by the Office of the Secretary of Defense and the Arms Control and Disarmament Agency. The United States is also prepared to examine space arms control issues in the Conference on Disarmament (CD). However, no arrangements or agreements beyond those already governing military activities in outer space have been found to date that are judged to be in the overall interest of the United States and its Allies. The factors that impede the identification of effective ASAT arms control measures include significant difficulties of verification, diverse sources of threats to U.S. and Allied satellites, and threats posed by Soviet targeting and reconnaissance satellites that undermine conventional and nuclear deterrence.

Notwithstanding these difficulties, the United States is continuing to study space arms control, in search of selected limits on specific types of space systems or activities in space that could satisfactorily deal with problems, such as those described above. Until we have determined whether there are, in fact, practical solutions to these problems, I do not believe it would be productive to engage in formal international negotiations. The United States remains ready, however, to examine the problems and potential of space arms control at the Conference on Disarmament in Geneva.

The attached Report on U.S. Policy on Antisatellite Arms Control sets forth in greater detail the views of my Administration on this important issue. It is unclassified and is suitable for general release. As you are aware, information regarding certain U.S. and Soviet space activities involves sensitive information. Accordingly, I am also transmitting a classified Report providing such information under separate cover. In preparing both Reports, every effort was made to respond to the questions asked by various Committees and Members of Congress.

Sincerely,

RONALD REAGAN.

REPORT
TO THE CONGRESS
ON
U.S. POLICY
ON ASAT ARMS CONTROL

31 MARCH 1984

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REPORT TO THE CONGRESS

U.S. POLICY

ON

ASAT ARMS CONTROL

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REPORT TO CONGRESS

U.S. POLICY ON ASAT ARMS CONTROL

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REPORT TO CONGRESS

U.S. POLICY ON ASAT ARMS CONTROL

Preface

The Congressional conference report for the Department of Defense Appropriations Act for the Fiscal Year ending September 30, 1984 states:

> The conferees agree to provide $19,409,000 for advance procurement for the Antisatellite (ASAT) program as proposed by the Senate, instead of no funds as proposed by the House. However, the conferees direct that these funds not be obligated or expended until 45 days following submission to the Congress of a comprehensive report on U.S. policy on arms control plans and objectives in the field of ASAT systems. In no event shall such report be submitted later than March 31, 1984. Such report should include specific steps the Administration contemplates undertaking, within the context of U.S. - Soviet negotiations, to seek a verifiable agreement with the Soviet Union to ban or strictly limit existing and future ASAT systems. The report should be unclassified, with classified addenda as required, and suitable for general release.

This Report to Congress fulfills that requirement. It summarizes U.S. national security requirements pertaining to ASAT weaponry, and the problems and possibilities for ASAT arms control. The Report is in two versions, one is unclassified and the other, containing additional detail, is classified.

U.S. POLICY ON ASAT ARMS CONTROL

I. Overview

U.S. arms control policy must serve our fundamental national security objectives. In particular, arms control arrangements should reduce the risk of war (through measures which strengthen deterrence, increase confidence, and enhance strategic stability) or reduce the destructiveness of warfare. Arms control arrangements for space are desirable if they contribute to our overall deterrence posture and reduce the risk of conflict, not as ends in themselves. Similarly, possible limits or bans on anti-satellite (ASAT) arms must be judged not only in their ability to limit damage to space objects, but also in their contribution to achieving the basic objectives of arms control with respect to terrestrial conventional and nuclear conflict.

The U.S. National Space Policy, announced by the President July 4, 1982, is consistent with the long-standing U.S. approach to space arms control in previous agreements. It states:

> "The United States will continue to study space arms control options. The United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapons systems, should those measures be compatible with United States national security."

Guided by these criteria, the United States has been studying a range of possible options for space arms control with a view to possible negotiations with the Soviet Union and other nations, if such negotiations would serve U.S. interests. The United States is also prepared to examine space arms control issues in the Conference on Disarmament (CD). However, no arrangements or agreements beyond those already governing military activities in outer space have been found to date that are judged to be in the overall interest of the United States and its Allies. The factors which impede the identification of effective ASAT arms control measures include significant difficulties of verification, diverse sources of threats to U.S. and Allied satellites and threats posed by Soviet targeting and reconnaissance satellites which undermine conventional and nuclear deterrence.

Notwithstanding these difficulties, the United States is continuing to study space arms control, in search of selected limits on specific types of space systems or activities in space which could satisfactorily deal with problems such as those described above. Until we have determined whether there are, in fact, practical solutions to these problems, we do not believe it would be productive to engage in formal international negotiations. The United States remains ready, however, to examine

the problems and potential of space arms control at the Conference on Disarmament.

II. ASAT Arms Control Considerations

U.S. policy toward limiting arms in space is part of the overall U.S. commitment to effective arms control. This commitment is reflected, for example, in our proposals in START, INF and MBFR for achieving substantial, verifiable reductions in nuclear and conventional forces, and in U.S. proposals for a chemical weapons ban. This commitment also is basic to the U.S. approach to space arms control. The United States is party to, and had a lead role in negotiating, a number of major international agreements that apply to space, including the Outer Space, Anti-Ballistic Missile (ABM) and Limited Test Ban Treaties. In addition, the United Nations Charter is expressly made applicable to space activities by the Outer Space Treaty.

These agreements provide a substantial, existing body of law regarding space arms control. Included in existing law is a ban on testing, orbiting, or stationing of nuclear weapons or other weapons of mass destruction in space; a ban on placing military installations on celestial bodies; a ban on development, testing and deployment of space-based ABM systems or their components; and a requirement for appropriate international consultations before conducting any activity or experiment that would cause potentially harmful interference with other countries' peaceful space activities.

United States arms control policy and plans for ASAT systems, as well as for any space weapons generally, result from an examination of a broad spectrum of factors. These factors relate to military activities in space and other activities regarding conventional and nuclear weapons, U.S. foreign policy activities and even U.S. commercial and scientific uses of space. In fact, ASAT arms control appears to span a greater breadth of subjects than any other area of arms control.

Previous ASAT Talks

At the initiative of the United States, bilateral negotiations between the US and USSR on control of anti-satellite weapons were held in 1978-79. These talks involved an extensive discussion of some of the problems of space arms control, and revealed major differences between the two sides. Further U.S. study since then has brought the whole topic of space arms control into sharper focus.

Potential Benefits of Space Arms Control

The potential benefits of any ASAT control regime would depend on both its framework and its details. The spectrum of possible space arms control measures includes bans on specialized

ASAT weapons and much less ambitious undertakings. To be acceptable any measure must be equitable, effectively verifiable and compatible with our national security. If any space arms control measures met these criteria, and were complied with, then they would have a number of potential benefits. For example, depending on the scope and effectiveness of an agreement, it might:

1. Limit specialized threats to satellites and constrain future threats to such key satellites as those for early warning. Such limitations on specialized threats to satellites, together with satellite survivability measures, could help preserve and enhance stability.

2. Raise the political threshold for attacks against satellites. Restricting threatening activity and/or prohibiting attacks on satellites would add to existing international law aimed at lowering the likelihood of conflict in space.

3. Meet some international concerns regarding the use of space for military purposes.

Problems Facing ASAT Arms Control

In addition to the potential benefits of space arms control, a balanced study of this topic must take into account a number of problems. These include: the need for effective verification; the potential for breakout; the risks of disclosing sensitive information; the problems of definition of space weapons; the vulnerability of satellite support systems; and Soviet military space activity.

Verification. Effective verification is fundamental to arms control. This applies to space arms control as it does to arms reductions in other fora. The Congressional language mandating ASAT arms control efforts has been uniformly specific on the matter of verification: any ban on ASAT systems is to be verifiable.

In general, verification of arms control agreements suffers from the extremely asymmetric degree of openness between the United States and the Soviet Union. The open U.S. society makes the Soviet task of monitoring U.S. activities regarding arms control compliance a relatively easy matter. In contrast, the closed Soviet society and the general Soviet tendency toward secrecy make U.S. monitoring and verification of compliance much more difficult. This problem is aggravated for ASAT systems because the satellites which serve U.S. and Allied security are few in number. Cheating on anti-satellite limitations, even on a small scale, could pose a disproportionate risk to the United States.

In this regard, the Soviets would have a far easier problem of verifying compliance with limitations on the U.S. ASAT

system than we would have on the Soviet system. For example, a ban on all ASAT systems would require that the Soviet ASAT interceptor system be eliminated. The Soviet interceptor is relatively small and is launched by a type of space booster that the Soviets use for other space launch missions. It is not clear how many interceptors or boosters have been manufactured. The USSR could maintain a covert supply of interceptors which could be readied quickly for operational use, probably without risk of U.S. detection. Launch vehicles could be diverted from other missions to launch ASAT interceptors.

Verification problems apply to other aspects of space arms control as well. For instance, tests of a ground-based laser ASAT weapon could be concealed. In addition, determining with confidence whether an object hundreds of kilometers above the earth has been damaged could, in practice, be extremely difficult, and from what source it had been damaged could be extremely difficult or impossible. It may be difficult to determine whether a satellite has been damaged by electronic countermeasures. It is also difficult, or in some cases could be impossible, to determine whether an orbiting satellite contains a weapon.

Additional verification problems arise if ASAT testing is banned or limited. The wide variety of ASAT systems listed below in the discussion of problems of definition, and the fact that ASAT capabilities can be a by-product of systems developed for other missions, create problems of identifying what would be prohibited under testing limitations. The fact that ASAT capabilities are inherent in some systems developed for other missions or are amenable to undetected or surreptitious development makes it impossible to verify compliance with a truly comprehensive testing limitation that would eliminate tests of all methods of countering satellites. Test bans for a more limited class of ASAT systems may be verifiable, and these are being studied to determine if they are in our national interest. The breakout potential of that limited class of ASAT systems is very troublesome and creates doubt that limited test bans could be effective.

The difficult verification problems could, in some cases, be mitigated by future technological developments, or by cooperative measures contained in future arms control agreements. Such possibilities are under study.

Breakout. Among the criteria which must be used in evaluating the implications for national security of any potential arms control measure is that of "breakout." This is the risk that a nation could gain a unilateral advantage if the agreement ceased to remain in force for any reason, for example through sudden abrogation, and obtain a head start in building or deploying a type of weapon which has been banned or severely limited. The importance of certain critical U.S. satellites, which are limited in numbers, could create an incentive for the Soviets to maintain a breakout capability.

Breakout potential could exist even if the Soviets, upon agreeing to a ban on ASAT systems, were to destroy all of their existing systems. The Soviets could retain the capability to redeploy quickly a system in which they would have confidence. If prior to the ban the United States had not tested its MV ASAT system, the Soviets alone would possess such proven technology. It might take the Soviets a year or less to deploy their system again.

Under a strict ASAT arms control regime, it is conceivable that the Soviets could change the basic character of their ASAT program. The USSR could have additional ASAT capability in equipment amenable to undetected or surreptitious development, which could be brought to operational status, or to a status that would permit rapid breakout. For example, any nation routinely conducting space rendezvous and docking operations, as the USSR does, could, under the guise of that activity, develop spacecraft equipped to maneuver into the path of, or detonate next to, another nation's spacecraft. Other types of systems amenable to such development include ballistic missiles with modified guidance software such as ICBMs, SLBMs and MRBMs, as well as space boosters with nuclear payloads. There is little reason to believe that the USSR would use any of these non-optimum capabilities in lieu of the systems with known ASAT capabilities. However, a ban on the more readily identifiable ASAT systems could increase the likelihood that other systems would be covertly developed to have ASAT capability.

Disclosure of Information. While the difficult verification problems associated with ASAT arms control might be decreased with the establishment of cooperative measures, in some instances these measures could cause other problems. Information regarding certain U.S. space systems that are associated with national security is among the most sensitive information within the government. Cooperative measures with the objective of enhancing verification of an ASAT arms control agreement might require access to U.S. space systems that were alleged by the Soviets to have ASAT capabilities, and hence could create an unacceptable risk of compromising the protection of that information. Such measures could also have adverse effects on civil uses of space.

Definition. It is difficult to define what constitutes a space weapon for arms control purposes. There are technologies and systems designed for purposes other than ASAT, even some with little or no ASAT capabilities, which may be difficult to exclude from an ASAT definition. Likewise, there are technologies and systems which could have an ASAT application that might not be included in an ASAT definition.

The U.S. Congress has shown concern over space system survivability problems, especially in legislation which each chamber has passed relating the U.S. ASAT program to arms control. The Senate passed a measure to establish criteria

governing the testing of ASAT warheads; in the deliberations over that provision, it was argued that "unless (ASAT) development is stopped, our most important and sensitive military satellites will be in jeopardy." The House of Representatives passed a measure deleting advanced procurement funds for the U.S. ASAT program; in those deliberations, it was argued "that the survival of current and projected U.S. space systems is vital to the national security of the United States." In keeping with those broadly-based satellite survivablity concerns we need to recognize that "ASAT capability" relates to all systems capable of damaging, destroying or otherwise interrupting the functioning of satellites. Such systems include:

-- maneuvering spacecraft (equipped to maneuver into the path of, or to detonate next to, another nation's spacecraft) such as the coorbital interceptor operationally deployed by the USSR.

-- Direct ascent interceptors such as exo-atmospheric ABM missiles, ballistic missiles with modified guidance logic, space boosters carrying nuclear payloads, and homing vehicles such as the miniature vehicle system undergoing development by the United States.

-- Directed energy weapons such as lasers and particle beams, (either ground-based or space-based, having sufficient power to damage satellites or their sensors).

-- Electronic countermeasures of sufficient power output to damage or interrupt satellite functions.

-- Weapons which could be carried by manned space planes or orbital complexes.

Furthermore, problems of weapon definition are compounded because some non-weapon space systems, including civil and commercial systems, could have characteristics which would make it difficult to frame a definition to distinguish them from weapon systems. An effective space arms control measure should take into account weapon capabilities beyond those of specialized ASAT systems, and at the same time it must not unduly constrain the legitimate functions of non-weapon space systems.

In seeking ways to verify an ASAT weapon ban, the Administration has been confronted with critical definitional problems: (1) there are many different types of systems which could be used to destroy satellites; (2) in general, many activities related to space give rise to capabilities inherently useful for ASAT purposes, for example, the rendevous and docking operations routinely conducted by the Soviets could be used to attempt to conceal development of one or more types of ASAT techniques, and (3) restricting the definition of what is an ASAT weapon could make an agreement easier to verify, but ineffective in achieving

its purpose of protecting satellites. These definition problems interact with and compound the verification problems described above.

Vulnerability of Satellite Support Systems. ASAT arms control would not provide for survivability of all components of space systems. For example, attacks on other elements of a space system (e.g., ground stations, launch facilities, or communications links) may in some cases be easier and more effective than attacks on satellites themselves. Attacks on ground-based support systems can be carried out with strikes by conventional weapons, such as by cruise missiles with conventional warheads launched from ships or aircraft.

The Soviet Non-Weapon Military Space Threat. Examination of space arms control needs to include a discussion of the growing threat posed by present and projected Soviet space systems which, while not weapons themselves, are designed to support directly the USSR's terrestrial forces in the event of a conflict. These include ocean reconnaissance satellites which use radar and electronic intelligence in efforts to provide targeting data to Soviet weapon platforms which can quickly attack U.S. and Allied surface fleets. In view of the fundamental importance of U.S. and Allied access to the seas in wartime, including for Allied reinforcement by sea, the protection of U.S. and Allied navies against such targeting is critical. Furthermore, as Soviet military space technology improves, the capabilities of Soviet satellites that can be used for targeting are likely to be enhanced and represent a greater threat to U.S. and Allied security. This point is explained at greater length below.

III. National Security Considerations Regarding Space

Beyond the significant limitations inherent in space arms control discussed above, other national security interests must be taken into account. These would pertain even if verification were not so significant a concern.

Strengthening Deterrence

A fundamental purpose of defense and arms control policies is to maintain and strengthen deterrence, both conventional and nuclear deterrence. ASAT limitations could, unfortunately, undermine deterrence in some instances.

Since the Soviet Union has an operational capability to destroy satellites while the United States does not, the current situation is destabilizing. If, for example, during a crisis or conflict, the Soviet Union were to destroy a U.S. satellite, the United States would lack the capability to respond in kind to avoid escalating the conflict. Thus, in present circumstances a U.S. capability to destroy satellites clearly responds to the need to deter such Soviet attacks on U.S. satellites in a crisis or conflict.

A comprehensive ASAT ban would afford a sanctuary to existing Soviet satellites designed to target U.S. naval and land conventional forces. The absence of a U.S. ASAT capability to prevent Soviet targeting aided by satellites could be seen by the Soviets as a substantial factor in their ability to attack U.S. and Allied forces and might offset Soviet concerns about the effectiveness of U.S. and Allied naval warfare capabilitiies. Uncertainty over their ability to employ satellites to target naval forces would decrease the Soviet perception of their chance for success, thereby adding to deterrence and stability. A U.S. ASAT capability would contribute to deterrence of conventional conflict.

For US and Allied security, the United States must continue its efforts to protect against threatening satellites. ASAT capabilities complement the other measures that must be used throughout a conflict. To do otherwise would undermine both conventional and nuclear deterrence. (Further discussion of the above factors is provided in the classified version of this report.)

For these fundamentally defensive reasons, the President has called for a prudent, measured response to the Soviet military space threat in order to protect U.S. and Allied security interests. In his National Space Policy statement he said:

> The United States will develop and maintain an integrated attack warning, notification, verification and contingency reaction capability which can effectively detect and react to threats to United States space systems. The United States will proceed with development of an anti-satellite (ASAT) capability, with operational deployment as a goal. The primary purposes of a United States ASAT capability are to deter threats to space systems of the United States and its Allies and, within such limits imposed by international law, to deny any adversary the use of space-based systems that provide support to hostile military forces.

Soviet Threats to U.S. Satellites

The current Soviet ASAT capabilities include an operational orbital interceptor system, ground-based test lasers with probable ASAT capabilities, and possibly, the nuclear-armed GALOSH ABM interceptors, and the technological capability to conduct electronic warfare against space systems.

The orbital interceptor must go into approximately the same orbit as its target and close at a specific velocity. There have been more than a dozen tests of the interceptor system, which we consider operational, including testing during a Soviet strategic forces exercise in 1982.

A Soviet high-altitude orbital interceptor capability is a possible threat, but we have no direct evidence of such a program

by the Soviets, and we may not obtain such evidence before testing. Other techniques for accomplishing this objective may appear preferable to the Soviets. For example, they could also use their developing electronic warfare capabilities against high-altitude satellites. We cannot now say which, if any, such high-altitude capabilities may be developed by the USSR.

Continuing, or possible future, Soviet efforts that could produce ASAT systems include developments in directed energy weapons. We have indications that the Soviets are continuing development of ground-based lasers for ASAT applications. In addition, we believe the Soviets are conducting research and development in the area of space-based laser ASAT systems. We have, as yet, no evidence of Soviet programs to develop ASAT weapons based on particle beam technology.

(Additional data concerning Soviet threats to U.S. satellites are contained in the classified version of this report.)

U.S. Satellites Threatened

While these numerous potential Soviet threats to U.S. satellites must be taken seriously, an immediate need is to address known Soviet ASAT capabilities. The operational Soviet coorbital ASAT system threatens U.S. low altitude satellites. In addition, there is a possibility that some sensors on some U.S. satellites could be damaged by ground-based Soviet lasers. Capabilities which have been or could be surreptitiously developed possibly threaten all U.S. satellites up to geosynchronous orbits. (More data concerning U.S. satellites threatened by Soviet ASAT capabilities are provided in the classified version of this report.)

Options to Counter Soviet Threat to U.S. Satellites

Deterrence provided by a U.S. ASAT capability would inhibit Soviet attacks against U.S. satellites, but deterrence is not sufficient to protect U.S. satellites. Because of the potential for covert development of ASAT capabilities and because of the existence of non-specialized weapons which also have ASAT capability, no arms control measures have been identified which can fully protect U.S. satellites. Hence, we must continue to pursue satellite survivability measures to cope with both known and technologically possible, yet undetected, threats.

Over the past several years the United States has begun to incorporate survivability features into various satellite systems. In addition, the Department of Defense has recently initiated a major review of survivability of not only the satellites but also the communication links and ground systems which support them. The purpose of this effort is to review potential vulnerabilities and to identify further survivability measures for implementation.

Enhancing space system survivability requires a variety of measures. For example, satellite maneuverability helps protect

against ASAT interceptors. Maneuver, however, is a costly tactic in that it shortens satellite mission lifetime and perturbs the satellite's orbital characteristics. Hardening satellites can improve defenses against directed-energy and nuclear weapons, but this tactic provides little effectiveness against a direct nuclear attack. Electronic counter-countermeasures could thwart some electronic warfare tactics directed against U.S. satellites. Another potential survivability measure would be to develop a capability to shoot back at threatening systems. Even more than those options previously stated, shooting back involves a number of severe mission penalties. In sum, these defensive measures add to satellite costs, reduce useful payload weights, shorten mission life time, and add to system development and testing complexity; no single defensive measure is totally effective against all threats.

A different category of defensive measures would involve the use of orbital spares and changing the current U.S. satellite replacement philosophy. By procuring sufficient satellite and booster spares, the United States could persue a launch on demand strategy for the most critical space capabilities. This strategy, combined with the use of stored spares on-orbit, might circumvent the effectiveness of a Soviet ASAT assault. This philosophy runs counter to current U.S. trends of developing space systems of greater sophistication and longer expected useful mission life. In sum, this option would require considerable investment, not now envisioned, in boosters, spacecraft production, launch facilities, and ground support.

The table shows in generic terms the satellite survivability features applicable to potential threats to space systems.

U.S. ASAT Program

The U.S. ASAT system presently under development consists of a miniature vehicle (MV) warhead mounted on a two-stage SRAM/Altair booster. This is carried aloft and launched from a specially modified F-15 aircraft. The MV will be capable of attacking satellites in low altitude orbits. The system is currently undergoing testing. It is to be deployed at one Air Force base on each coast of the United States.

The United States has no plans to extend the altitude capability of the MV ASAT system to place high altitude satellites at risk. We are, however, continuing to review ways in which U.S. ASAT capability could be improved. The U.S. ASAT program is being conducted in a manner fully consistent with all U.S. obligations including the ABM and Outer Space Treaties.

Directed energy weapons technologies, including high energy lasers have the potential for ASAT use. These technologies are in the research and development phase.

(Further data on the U.S. program are contained in the classified version of this report.)

ASAT CAPABILITY	POTENTIAL PROTECTIVE MEASURES				
	Maneuver	Harden/ Shield	Orbital Spares	Replen- ishment	Shoot Back
Coorbital					
Nuclear	X		X	X	X
Non-Nuclear	X		X	X	X
Direct Ascent					
Nuclear	X	X	X	X	X
Non-Nuclear	X		X	X	X
Ground-Based Directed Energy					
Lasers	X	X		X	
High Power RF	X	X		X	
ECM		X		X	
Other Space Platforms with Weapons					
Lasers		X			
Particle Beam					
High Power RF		X		X	
Non-Nuclear	X				X
ECM		X		X	

"X" indicates measures that could be used with varying effectiveness to improve satellite survivability against possible threats. As noted in the text, each defensive measure implies increase in cost and/or significant mission penalties and no single measure is totally effective against all threats.

Utility of a U.S. ASAT Capability

The U.S. ASAT program is focused explicitly on those Soviet satellites which threaten U.S. and Allied terrestrial interests in time of war. All of these threatening Soviet satellites operate at low altitude. Without low altitude satellites to confirm detections of terrestrial targets, Soviet space-based targeting data would be significantly degraded. While the U.S. MV ASAT will be able to attack only a portion of the Soviet satellites, in doing so it would be able seriously to degrade the Soviet reconnaissance capability and thus serves U.S. deterrence objectives. It cannot and need not attack Soviet early warning satellites at high altitudes.

Because of their high launch rates and payload capacity, the Soviet space force has the inherent resiliency to make replacement of satellites a viable alternative (as long as ground facilities are intact). On-orbit spares, surge of launches in a crisis or prior to a hostility, and satellite replacement following ASAT attack are possible methods of replenishment. The U.S. program is structured to provide a number of readily available ASAT systems sufficient to counter expected Soviet surge and replenishment.

Possible Soviet Counters to the U.S. MV ASAT

The U.S. MV ASAT was designed with possible Soviet counters in mind. Maneuvering to avoid intercept is the most frequently discussed countermeasure which the Soviets could employ. It is not clear that the Soviets have the capability to determine which satellite would be the target of a given attack and thus would have to maneuver several of their satellites each time the U.S. launched or simulated the launch of an ASAT interceptor. Because repeated maneuvers would reduce Soviet satellite lifetimes, maneuver would be a costly countermeasure. Although the Soviets could, in the future and at some expense, increase their satellite maneuver capability, this could be offset by U.S. satellite tracking improvements planned for other purposes.

Raising somewhat the orbital altitude of certain existing Soviet low altitude satellites could improve their survivability, but would impair their performance. Only if the Soviets deployed at this new altitude a new targeting capability similar to their existing capability at the lower altitude would the United States need to counter such a capability, for example, by developing a larger booster for the ASAT MV.

Soviet use of simple decoys to improve satellite survivability could be countered by changes in ASAT sensor logic. Complex decoys might require changes in Soviet satellites which could take many years.

Alternatives to Offset the Threat Posed by Soviet Satellites

U.S. force structure plans include a balanced package of complementary defensive measures. The capability to counter Soviet satellites is an important element of those plans. To the extent that we limit our capabilities to counter Soviet satellites, we tend to increase our need to augment our conventional forces to perform their terrestrial missions in the face of the Soviet threat from space, with attending costs.

To counter Soviet satellites by attacking their ground facilities would be an uncertain alternative to an ASAT capability and one which risked escalation of a conflict. A U.S. ASAT capability is a less risky and more effective and flexible way to deal militarily with the Soviet space-based threat.

The ASAT MV compléments other protective measures which must be used throughout a conflict. These measures include communications and emissions security, evasive maneuvers and electronic countermeasures. These countermeasures are, however, reactive and cannot provide permanent protection. Moreover, they can impose sharp constraints on the operational effectiveness of U.S. forces in a conflict.

IV. Arms Control Prospects in Light of Policy and National Security Considerations

The balance between the benefits and risks of ASAT arms control is quite sensitive. For example, there is a dilemma as to whether arms control restrictions that would constrain our ability to deal with Soviet targeting satellites, are in our national security interest. Our need to counter such Soviet satellites so as to support our terrestrial forces must be balanced against our interest in limiting threats to critical U.S. satellites. Our studies of possible ASAT arms control regimes are considering these concerns.

Soviet ASAT Arms Control Activities

Although the Soviets have periodically tested their operational ASAT interceptor, they regularly advance space arms control measures in international fora, without acknowledging their own ASAT capability. In their latest initiative last August, the Soviet Union submitted to the 38th United Nations General Assembly a draft treaty, the stated objectives of which are to prohibit testing and deployment of space-based weapons. It calls for elimination of existing ASAT systems, for a ban on the development of new ASAT weapons, and for a ban on attacks on satellites. The USSR also announced a "unilateral moratorium" on the launching of any type of ASAT weapon, to remain in effect as long as other countries refrain from putting into space ASAT weapons of any type.

U.S. Evaluation of Soviet Initiatives

The wording of these proposals had certain ambiguities and loopholes. For example, it would appear that the moratorium did not cover tests of ground-based systems, such as lasers. In any case, the Soviet moratorium appeared to be designed to block tests of the U.S. miniature vehicle ASAT interceptor, while allowing the USSR to maintain the world's only operational ASAT system. This is inconsistent with the USSR's profession "not to be the first to put into outer space any type of ASAT weapon."

The Soviet initiatives have fundamental shortcomings. Lack of effective verification is one of the major weaknesses of the draft treaty. It provides for national technical means of verification, but nothing beyond that. Indeed, the draft does not even prohibit actions that would impede verification. In addition to the problem of verifying the elimination of the Soviet ASAT system, the draft treaty's proposal for a ban on destruction, damaging, and disruption of other states' space objects could also pose verification problems. The Soviet draft treaty is unclear with regard to Soviet targeting and reconnaissance satellites. The draft also does not deal with residual ASAT capabilities. For example, dismantling of the Soviet co-orbital ASAT system would still leave the USSR the option of using some of its Galosh ABM interceptor missiles in an antisatellite role. In addition, the draft treaty proposes that "piloted" spacecraft not be used for "military purposes." We strongly suspect that this provision is intended to constrain the use of the U.S. Space Transportation System (the Space Shuttle), which in the years ahead will serve as the primary U.S. launch system for national security as well as civil space missions. At the same time, the treaty would apparently not constrain the Soviet unpiloted space station.

Similarly, the possible motives behind the Soviet offer of a "moratorium" are suspect. In addition to their operational ASAT system the Soviets currently have other systems with ASAT capability. The Soviet moratorium deals only with their operational system, allowing the others to continue. For example, the Soviets could test ground-based lasers in an ASAT mode without violating their moratorium. Moreover, the Soviet offer came on the eve of the commencement of flight testing of the U.S. MV system. Thus, the timing suggests that the Soviet offer is designed to curtail the U.S. MV program and thereby leave the Soviet Union with a unilateral advantage in ASAT capability. Furthermore, a test moratorium would not necessarily cause their operational system to atrophy: after a hiatus of several years in ASAT testing, the Soviets were able to resume testing of their ASAT system without any apparent degradation in its performance. Programs in research and development pay a much higher price for a test moratorium. Even a short delay in the test program would delay the time that the U.S. ASAT could be operational. This would decrease the Soviet incentive to negotiate in good faith. (A full analysis of the Soviet draft treaty is provided in the classified version of this report.)

It appears that the Soviet objectives in their initiatives are to limit disproportionately the U.S. ASAT capability and to enhance the Soviet international image.

In sum, it appears that Soviet initiatives on ASAT arms control pose profound verification problems, as in the case of the Soviet treaty, or would leave the USSR with a destabilizing advantage, as in the case of both the treaty and the moratorium.

Multilateral Space Arms Control Activities

The United States has supported discussion of a broad range of questions on space arms control at the Conference on Disarmament (CD). The United States supported in 1983 the establishment of a CD Working Group on Outer Space. The United States does not favor having a working group undertake negotiations. Rather, we believe that a working group should address a broad range of space arms control issues, beginning with a thorough examination of the existing legal regime for space, before any conclusions can be drawn about negotiations which might be pursued in the CD. In 1983, the Soviets insisted that a working group on outer space in the CD be commissioned to begin negotiations. While the United States, our Allies, and the neutral and non-aligned nations of the CD all were ready to establish a working group without authority to negotiate, the Soviets blocked such action. The U.S. position this year in the CD is unchanged: the United States remains ready to proceed with a serious and responsible examination in the CD of space arms control.

Future Directions of ASAT Arms Control

U.S. space arms control policy seeks to reduce the risk of conflict and enhance strategic stability. Consistent with this purpose, the Administration has been evaluating a number of possible ASAT arms control options in light of whether they support our overall deterrence posture and are effectively verifiable. Despite efforts by this and the previous administration, no way has yet been found to design a comprehensive ASAT ban that meets these criteria.

The major problems for ASAT arms control discussed in detail in this report have hindered our efforts to develop effective arms control measures. In fact, it appears that the problems of verification tend to be greater the more comprehensive the limitation. Some less sweeping options under study would seek to limit or ban specific types of weapons systems. Since we must in any event be able to protect our satellites against threats that could be developed without our knowledge, there is a premium on finding ways to limit in arms control those ASAT systems that create the most difficult survivability problems. We are searching for limits on such systems which are effectively verifiable and which allow us to protect U.S. and Allied forces from threatening Soviet satellites, such as targeting satellites. Other options

under examination would regulate certain threatening activities related to space.

The future of space arms control must also be considered in the broader context of U.S.-Soviet arms control relations. Soviet actions in other negotiating fora and Soviet actions with respect to compliance with existing arms control agreements must also be taken into account to determine the most appropriate course of action for the United States concerning arms control for outer space. In the meantime, the U.S. evaluation of possible future courses for ASAT arms control will be judged not simply in light of their ability to limit damage to space objects, but also in light of their contributions to the basic objectives of U.S. arms control policy with respect to terrestrial conventional and nuclear conflict.

The door is not closed to effective ASAT arms control measures. As noted earlier, the President has said that the United States will consider verifiable and equitable arms control measures that would ban or otherwise limit testing and deployment of specific weapons systems, should those measures be compatible with U.S. national security.

This remains the policy of the Administration. The active search for viable arms control opportunities in the ASAT area is continuing.

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THE MILITARIZATION OF THE AMERICAN SPACE PROGRAM: AN HISTORICAL PERSPECTIVE

By CLAYTON R. KOPPES

The classical era of the American space program has come to an end. After a quarter century in which peaceful and scientific activities played the major role, the space program is veering toward domination by the military. The Reagan administration has given added impetus to this development in two important ways: it has drastically shifted resources from the civilian, scientific side to the military, and it has championed combat capability in space. Planetary missions have become endangered species. But in carrying out this landmark shift, the Reagan administration was able to build on the foundation afforded by crucial decisions in the civilian space program—specifically, John F. Kennedy's impetuous decision to send a man to the moon. The purpose of this article is to sketch the direction of the space program of the 1980's and to analyze the historical developments that prepared the way for this ominous turn from science to a possible "star war."

The first flight of the space shuttle *Columbia*, carrying a

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secret military cargo, was a harbinger of the 1980's becoming the decade of American military exploitation of space. The *Columbia* landed gracefully at the center of a carefully staged media event on July 4, 1982, at Edwards Air Force Base in California. Military brass bands blared, and spectators waved thousands of tiny souvenir stars and stripes on cue. President Reagan helicoptered over from his ranch near Santa Barbara for the 9:15 a.m. arrival of the astronauts, who stayed up for an extra orbit so that the chief executive would not have to be awakened early (a president's sleep is worth millions). Reagan used the occasion to deliver an important address on space policy.

Despite the attention showered on the shuttle, information about its flight was sparse. The Air Force refused to reveal the nature of the cargo, even though one suspected that it wasn't all that secret; the Air Force has maintained a policy of refusing comment on all shuttle cargoes, even weather satellites. A live television broadcast of the crew struggling with troublesome cargo-bay doors was not permitted; instead, film had to be recorded and then cleared by military censors. And when the astronauts finished their work, they received their congratulations from an anonymous official voice.

These proceedings contrasted sharply with a quarter century of relatively open operations under the National Aeronautics and Space Administration. Most early NASA missions were broadcast live; real people could be seen talking, and "no comments" were rare. NASA was established in 1958, in preference to a military-run space program, to give peaceful, scientific ventures an institutional home. The National Space Act of 1958 mandated the "widest practicable and appropriate dissemination of information concerning [NASA's] activities and the results thereof." The space program could not be neatly divided into civilian and military spheres, of course; space exploration had emerged from the military missile programs. The Department of Defense continued to play an important role in space but chiefly with "passive" devices such as surveillance satellites rather than weapons systems.

To Reagan, however, the prime use of space technology appears to be military. The keynote of his 1982 speech at Edwards Air Force Base was the use of space for American defense—in other words, preparation for a combat capability beyond the planet Earth. This was an attempt "to minimize the influence of policy statements extending back to the Eisenhower administration about U.S. peaceful uses of space," noted *Aviation Week & Space Technology*, the weekly Bible of the aerospace industry. Reagan, it said, intended to lessen the barriers between NASA and the military to create "two separate, distinct and strongly interacting programs."

The federal budget reflects these priorities. In 1982 military spending on space technology surpassed civilian expenditures for the first time since the early days of the program. For the next several years, the Reagan administration projects, military space spending will increase about 50 percent more than even the overall Defense Department budget. The space program will thus get an outsized chunk of what may prove to be the most critical legacy of Reagan politics: the shift of federal resources from social services to the military sector.

Planetary exploration—indeed, the scientific aspects of the space program in general—merited scant mention in the president's address. Reagan's lukewarm endorsement of planetary missions suggested that they would have to be squeezed out of budgetary leftovers, if any existed. The hemorrhaging in the federal budget, coupled with the hostility toward planetary programs exhibited by David Stockman and his budget office in 1981, raised widespread alarm that Reagan's speech presaged an end to American exploration of the solar system. Eventually a planetary program survived, but in a scaled-down, low-budget version which underscored the shift of resources to military purposes.

The space shuttle, which NASA grasped as a lifeline in the early 1970's, now epitomizes the growing military dominance of the program. The shuttle idea sat inert on the

launching pad until NASA gained support from the Air Force by promising to make significant design modifications to enhance the spacecraft's military utility. As costs spiraled and capabilities declined in the late 1970's, the shuttle faced further trouble. The Air Force again rode to the rescue, but each Pentagon endorsement carried a higher price tag. Military shuttle missions, once virtually nonexistent, grew to 30 percent of total missions. Now, through 1994, such missions stand at about 50 percent of the total and may well climb more. Yet NASA paid most of the shuttle's costs, and it offers the Pentagon a 32 percent discount from the commercial rate, which is already artificially low. NASA and the Air Force are tight-lipped about the military uses of the shuttle, although one activity may be repair and modification of U.S. satellites in orbit. And NASA has acknowledged, perhaps inadvertently, that astronauts wielding fancy wire cutters could disable twelve hostile satellites in seven days. An Air Force general runs the shuttle program; his executive assistant is an Air Force colonel. Thus the shuttle, once billed as a boon to scientific and commercial operations in space, has become a vehicle primarily for military missions.

Augmented by the shuttle, the Air Force stands on the threshold of realizing its longtime goal of controlling most space activities. In June 1982 it established a Space Command, putting space on an equal footing with the Tactical and Strategic Air Commands. This move clearly anticipates a combat capability. Gen. Lew Allen, Air Force chief of staff, expressed the hope that this new organization would absorb Navy and Army space activities in a single "unified command." Personnel in Air Force blue infiltrate today's NASA. The deputy administrator is Hans Mark, a former secretary of the Air Force. More than 150 Air Force officers and civilian employees are sprinkled through the Washington, Houston, and Cape Canaveral offices. Meanwhile, the Air Force is pouring more than $2 billion into its shuttle facilities, possibly in preparation for its takeover of the shuttle. Secretary of the Air Force Verne Orr remarked in 1982: "Most people in

the Air Force think far enough downstream. We will probably be running the shuttle." Even a name change has been tossed about: the Air Force may become the Aerospace Force.

Whatever its name, the Air Force objective is clear: military domination of the space program before the decade is out. Says Lt. Gen. Richard O. Henry, commander of the space division: "Space is revolutionizing warfare." Accordingly, space is seen as today's equivalent of the age-old military objective of the "high ground." For now, the Pentagon emphasizes upgrading "passive" uses—communications, surveillance, navigation, and weather forecasting. The defense satellite communications system, a network of ten orbiting satellites which soon will be augmented with a new generation of satellites at $50 million apiece, handles military and government communications worldwide. An 18-satellite global positioning system about to be deployed will allow receivers anywhere—even on man-carried packs—to tell their location within 1/100th of a mile. The system can also guide ballistic missiles with uncanny precision. The Reagan administration wants to spend nearly $20 billion over the next five years to expand and harden the network—much of it in space—for directing nuclear forces. These communication links assume particular importance for the newly fashionable notion of fighting a protracted nuclear war.

For the future, some politicians and Pentagon planners dream of real-life "Star Wars," with flashing lasers, particle-beam weapons, and the like. The president raised this possibility with his "Darth Vader" speech in March 1983—a technological companion piece to his "evil empire" ideological manifesto delivered a short time earlier. Reagan apparently envisions a network of orbiting satellites equipped with lasers that could destroy Soviet missiles within a few minutes of launch. He presented this scenario in the most hopeful of terms; this deployment would rescue Americans from the scourge of nuclear weapons. The militarization of space presumably would become the path to perpetual peace.

The president was responding to the deep-seated fear of nuclear war. But his prescription feeds the dangerous illusion that there is a defense against nuclear weapons. By focusing on a technological fix, this approach distracts energies from the key problem: dealing with the nuclear weapons themselves. Far from lending stability to the nuclear equation, the Reagan net may heighten the possibility of nuclear war. Once a hostile nation's incoming missiles were destroyed, the United States would have the option of launching its own nuclear strike undeterred by fears of retaliation. The Soviet Union would therefore have every incentive to knock the American lasers out of the sky or develop countermeasures, with all the risks such moves would entail.

But even apart from such considerations, it is doubtful that the Reagan lasers make strategic sense. Except for the Edward Teller coterie, most scientists treated the Reagan speech with skepticism or derision. They point out that the technological problems of crafting a system that would work with the necessary precision are probably insuperable. The logistical demands are formidable; perhaps 2,000 shuttle flights would be required to transport the heavy mirrors and the like into space. What is more, many scientists and arms experts, such as Harold Brown, President Carter's secretary of defense, argue that countermeasures would be easier and cheaper. This new space arms race could fuel a spiral of ever more arcane and dangerous, but inconclusive, technology. And it would entail the expenditure of untold billions. Brown thinks that Defense Department budget limitations will eventually derail any such project. "But it is less clear," he says, "that its enthusiasts can be prevented from spending some billions of dollars in a fruitless attempt."

Like the bomber and missile gaps of yore, the military turn in space is being sold as a response to the Soviet Union's transgressions. Familiar tactics, such as calculated leaks, distorted statistics, and lurid future possibilities, are prominent again. A pattern of the post-World War II arms race is repeating itself. Herbert York, onetime director of the Liver-

more Laboratory and the Defense Department's chief scientist, believes the United States bears a major responsibility for the arms race. In most areas of weapons development, it has long been ahead of the Soviet Union; in those where it has been behind, the scope and pace of the American response has triggered a new round of escalation. John Foster, former director of Pentagon research and engineering, candidly observed that two forces drive American military research and development: "Either we see from the fields of science and technology some new possibilities which we think we ought to exploit, or we see threats on the horizon, possible threats, usually not something the enemy has done, but something we have thought of ourselves that he might do, and we must therefore be prepared for." In short, the role of perception is crucial; rather than simply responding to the Soviet Union, the United States has usually held the initiative.

However alluring space as the complete battlefield may be to some enthusiasts, the United States has much to lose should space become an arena of active combat. America is ahead in military space technology, but it is more dependent on space-based systems than the Russians, who enjoy a geographically central position. The obvious alternative is a treaty that would ban antisatellite (ASAT) weapons. ASAT negotiations were sluggish in the late 1970's and collapsed after the Soviet invasion of Afghanistan. A group of prominent scientists and arms experts have appealed to the Reagan administration to resume negotiations on a treaty banning space weapons. The group includes men such as Lee DuBridge, former head of the California Institute of Technology and presidential science adviser, and William Pickering, the veteran director of the Jet Propulsion Laboratory who played a major role in forging the close relationship between science and the military during the Cold War. They warn that this is "close to the last moment" to keep space free of weapons. Once weapons are deployed there, it may prove all but impossible to remove them. If an ASAT treaty proves unat-

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tainable, Brown suggests at least trying to get two lesser goals: a declaration that "attacks on satellites are a hostile act prohibited in peacetime" and a "limitation—for example, to low altitudes—on development and deployment of anti-satellite capabilities."

The Reagan administration shows little interest, however, and recently reacted to a Soviet proposal for an ASAT treaty with indifference, if not contempt. It believes that massive military buildup is desirable in itself because of the strains such competition places on the Soviet economy. Arms control chief Kenneth Adelman stresses the problem of verification. This is a serious issue, to be sure. But the problem of verification curiously evaporates whenever the Pentagon, campaigning for new weapons systems, presents as gospel its charts and graphs of Soviet current strengths and future possibilities. As a result, in the words of the Center for Defense Information, "the race to militarize space is rapidly outpacing the modest diplomatic efforts to control it."

II

Whatever the future price of military space programs, a major cost already has been a reduction in our ability to explore the solar system. The most notable casualty has been planetary exploration—the brilliant series of missions to the terrestrial planets and beyond whose scientific returns provide perhaps the ultimate rationale for the space program. As the voracious shuttle consumed the NASA budget, important scientific missions wound up on the budget room floor, in particular the once-in-a-lifetime opportunity to intercept Halley's Comet in 1986 and the American spacecraft for the International Solar-Polar Year. At one point it appeared that David Stockman might even pull the plug on the *Voyager* mission enroute to Uranus and leave it to telemeter its path-breaking data back to a deaf Earth. Other nonmilitary programs, including space applications and aircraft research, have been severely cut.

The Jet Propulsion Laboratory in Pasadena, the world leader in planetary exploration, has converted to about 30 percent military funding after two decades of virtually no classified work. After retiring as Air Force chief of staff, Lew Allen became director of JPL on Oct. 1, 1982. Allen, who holds a Ph.D. in nuclear physics from the University of Illinois, is the first director from outside Caltech, JPL's nominal manager. He insists that JPL will retain its planetary and scientific ethos. But the Pentagon has captured a portion of the laboratory's activities permanently, with Caltech promising that JPL will not renege on its military contracts even if there should be a resurgence of civilian funding.

In the uproar over the 1981-82 budget cuts—"a lot of bad vibes and a lot of good dialogue"—modest signs of hope began to surface in late 1982. Planetary scientists and NASA officials mapped plans for new missions. The 1983 NASA budget proposal included the first new start since 1977, the Venus Radar Mapper. This mission is the half-price cousin of the $600-million Venus Orbiting Imaging Radar (VOIR). The arbitrary price cut significantly reduced scientific returns. Instead of 0.1-kilometer resolution over the whole planet, the new project offers 1-kilometer resolution over 70 percent of Venus. If approved during the 1983 budget cycle, Venus Radar Mapper could orbit the mysterious inner sphere by late 1988. "But whatever happens," observed M. Mitchell Waldrop in *Science,* "the mission does seem to represent a good-faith effort to give the Administration what it says it wants: high-payoff science at a minimal cost."

Even on the narrow grounds of national interest, this policy is shortsighted. As Harold Brown has pointed out: "At a time when U.S. technology is one of the few comparative advantages that this nation has, and one of the few instruments of American prestige and morale, it is foolish to let the space science and planetary exploration programs wither." The odds are high. For, if the new cut-rate missions cannot save the scientific and planetary side, in Brown's opinion, "it is

likely that the ability to carry out such programs will be lost for the rest of this decade."

Although the Reagan administration has made the trends to space militarization starkly clear, an historical perspective suggests that this military domination developed during the past 20 years—and is in large part due to NASA itself. The choice that set NASA on a trajectory so damaging to the civilian side was the decision to gamble most of its chips on the shuttle. That choice derived, in turn, from what might be termed the Apollo imperative: the necessity of finding a project big enough and costly enough to absorb at least some of the capacity created for Apollo.

The early years of the space program, under the Eisenhower administration, suggested an alternate approach that might have achieved many of the goals of Apollo but at less cost and with less long-term harm to the civilian space program. Established in 1958, the fledgling NASA embarked on a cautious course that tried to downplay "spectaculars" and keep science in the foreground. Heading the new agency was T. Keith Glennan, president of Case Institute of Technology in Cleveland and a former member of the Atomic Energy Commission. Glennan believed that the United States could not avoid competition with the Soviet Union in space, but he wanted to establish the terms of the competition. No "space cadet," he thought that putting a man on the moon was worthwhile, although not "a matter of prime importance." He favored a program with a budget of $2 billion to $2.5 billion per year that would make possible a manned lunar landing by about 1975. The preoccupation with prestige had little place among his priorities. For Glennan, American leadership involved much more than primacy in space. As he confided to his private diary: "When one starts to talk about the prestige of the United States resting on the question—'When do we get a man on the moon?'—it seems clear that all sense of perspective has gone out the window."

NASA under Glennan started a cautious man-in-space program, known as Mercury. The first astronaut, Alan Shep-

ard, lofted into space for a few minutes on May 5, 1961, became a national hero, although he did little more than go along for the ride. Glennan worried about the "circus" atmosphere surrounding the astronauts. Eisenhower, even more skeptical, was prepared to call for an end to the manned program in his last budget message, in January 1961. He chose less-categorical language, however, and still put science first: "Further testing and experimentation will be necessary to determine whether there are any valid scientific reasons for extending manned spaceflight beyond the Mercury program."

III

In retrospect, the civilian space program established under the Eisenhower administration appears ideal. It put peaceful, scientific goals first; it showed a healthy skepticism about the exaggerated profits of prestige. If putting a man on the moon was worthwhile, surely Glennan's step-by-step approach was preferable to the crash program actually undertaken. His plan allowed for a careful, evolutionary process rather than the exorbitant costs entailed by Apollo's concurrency—the development of new technologies simultaneously rather than in sequence. His plan also avoided the creation of a large extra capacity that would establish a momentum for additional Apollos after it was finished. Above all, it recognized that, as James R. Killian, Eisenhower's first science adviser and the president of MIT said, "the really exciting discoveries in space can better be realized by instruments than by man."

Any loss of prestige in the race to space by the United States was partly self-inflicted. Ironically, the U.S. obsession with getting ahead of the Soviet Union offered its adversary an advantage, as Glennan realized. After leaving office in January 1961, the NASA official suggested what Soviet leader Nikita Khrushchev could do—and, in fact, did: launch "a barrage of propaganda and successful spaceflights until he had the U.S. committed to a costly program"—and "then

withdraw from the 'race.' " Glennan's intuition was shrewd. Although some people believe that, because of its greater resources, the United States can easily outspend the Russians, the opposite may be more accurate. America's bountiful resources can create the illusion that all things are possible and, hence, that difficult choices need not be made. This illusion has come to haunt us since the spending sprees of the 1960's.

The spending spree on space projects began in earnest soon after John F. Kennedy became president in early 1961. To Kennedy, the "space gap" symbolized "the nation's lack of initiative, ingenuity, and vitality under Republican rule," according to his confidant Theodore Sorensen. "The President was more convinced than any of his advisers that a second-rate, second-place space effort was inconsistent with this country's security."

Other New Frontiersmen were more cautious. David E. Bell, the former Marine and Harvard economist who served as budget director, tried to put the space program in perspective. He objected to "full-scale participation in the 'weight lifting' and manned space-flight competitions." These activities impinged on other, more worthwhile parts of the budget. He argued for a strong scientific and technological program, as well as for space applications such as meteorology and communications. These would be at least as effective in building prestige, for they were "a specific token that we are more concerned with the problems of *men on earth* all over the world than we are with placing *men on the moon.*"

Kennedy ignored these balanced assessments, however, when he faced a disastrous week in mid-April 1961. On April 12 Soviet astronaut Yuri Gagarin became the first man to orbit the earth. Then on April 15 the Bay of Pigs invasion of Cuba began, and by April 19 the White House knew the operation was a fiasco. On that day Kennedy called Vice-President Johnson into the Oval Office and told him to find a "space program which promises dramatic results in which we could win." A few days later Johnson came back with the impro-

vised proposal for Apollo—a program to put a man on the moon by the end of the decade at a cost close to $35 billion—a price tag the Eisenhower administration had considered outrageously wasteful. Kennedy presented the Apollo project to a receptive Congress on May 25, 1961. Invoking familiar New Frontier Cold War imagery, he called Apollo essential "if we are to win the battle that is going on around the world between freedom and tyranny."

More than prestige was at stake. An aggressive man-in-space program enhanced American military prowess—one of the major goals of the Kennedy administration. The New Frontier fashioned what Sorensen proudly termed "the most powerful military force in human history—the largest and swiftest buildup in the country's peacetime history." The expansion ranged from counterinsurgency forces, such as the Green Berets, to the huge Minuteman missile fleet. NASA's manned activities not only furthered "the peaceful conquest of space but also helped create the building blocks for the future military missions which may be required," said Gen. Thomas S. Power, commander-in-chief of the Strategic Air Command. NASA estimated that three-fourths of the cost of Apollo went toward development of near-Earth orbital capabilities, which were essential for possible military missions, such as interception of "hostile space vehicles." NASA also financed most of the cost of the development of large launch vehicles and complex ground facilities. All these "building blocks" would be assembled for the shuttle and its military uses in the 1980's.

Although the Apollo program sped through Congress, most scientists were skeptical because Apollo seemed likely to produce relatively little scientific data in comparison to its enormous cost and yet was presented to the public as a scientific undertaking. The elder statesman of American science, Vannevar Bush, who had run the Office of Scientific Research and Development during World War II, pointed out that national prestige was "far more subtle" than NASA's "immature" concepts. He preferred a different Kennedy

innovation, the Peace Corps: "Having large numbers of devoted Americans working unselfishly in undeveloped countries is far more impressive than mere technical excellence," he said. Glennan presciently noted in private that the feverish excitement attached to the Apollo program "in the long run . . . could work strongly to our detriment."

IV

In the short run, Apollo promised a Christmas tree laden with treats. Since the shift from bombers to missiles threatened the stability of the aircraft industry, a big space program was a godsend. A senior engineer at JPL observed that the companies argued that "our country is plagued with being too efficient in its production for its own economic good, and hence that inefficient production such [as] is generated by making planes or missiles that will in all probability never be used is essential to economic stability." He observed sardonically of the space program: "It is certainly possible to spend large sums of money in inefficient production in this area."

Apollo enjoyed an ardent advocate in Kennedy's NASA administrator, James E. Webb. A dynamic capitalist Cold War warrior, Webb epitomized the post-World War II American businessman who shuttled between corporate board room and government suite. He served as President Truman's budget director and under secretary of state, then went on to run one of Oklahoma Senator Robert Kerr's oil companies and sit on the board of McDonnell-Douglas, the giant aerospace contractor. Webb stressed the quasi-military aspects of the space program in relation to the Cold War. He warned that "the population not adequately disciplined to carry out large-scale organized efforts, such as are required in wartime, and which are now manifest in the space program, . . . may be subject to the disintegration" that afflicted Rome. Webb skillfully forged an alliance of Sunbelt politicians and the politically potent aerospace firms. Most of the space business went to the Sunbelt. The Johnson Manned Space Center, for

example, landed in Houston, the home district of Congressman Albert Thomas, who chaired the House committee controlling NASA's budget. Webb wooed industry with a profusion of multi-billion-dollar contracts. "The result," *Fortune* concluded, was "an intimate new sociology of space, a new kind of government-industrial complex in which each penetrates the other so much that sometimes it is hard to tell which is which."

Apollo grew to dominate NASA. It took the lion's share of the budget, and its presence distorted other aspects of the space program, particularly the scientific projects. Ranger and Surveyor, two lunar precursors of Apollo, for instance, had mainly scientific objectives. Yet when the NASA budget got tight, in the mid-1960's, the last blocs of Ranger and Surveyor missions, which would have made possible a complete mapping of the moon, were canceled so as not to jeopardize Apollo.

The project reached its goal when Neil Armstrong took his "giant step for mankind" from the *Eagle* in July 1969. Apollo was an engineering landmark, as $30 billion projects tend to be, and it was not without its benefits for science. Nevertheless, the $30 billion showered on Apollo could have returned immeasurably greater scientific knowledge had it been applied to instrumented space exploration. And, ironically, the United States could not fully savor Apollo's expected dividends for national prestige since some of the same fixations about Communist advancement that had produced Apollo also plunged the United States into Vietnam. Much of the prestige America hoped to gain on the surface of the moon had already been lost in the jungles of Southeast Asia by the summer of 1969.

Now that Apollo had reached home port safely, what next? The public might remember Neil Armstrong, but would it remember the third astronaut on the moon, or the fifth? What would NASA, and the firms it had wooed, do for an encore? The "new sociology of space" had ominous long-term implications. The huge buildup of plant capacity, the throngs of

aerospace engineers who needed jobs, and the bureaucratic drives of a typical federal agency all created a momentum to find a program to fill Apollo's shoes.

One idea was to apply Apollo technology and scale to the planetary program. NASA promoted *Voyager*, a giant orbiter-lander combination larger than any planetary spacecraft designed to date, for a mission to Mars in 1973. The weight of the spacecraft would be almost enough to accommodate a manned mission to the red planet—a not-so-secret wish of some space enthusiasts. The Voyager project would cost at least $2 billion and would allow NASA to boost the cost of the planetary program from the range of $50 million to $500 million annually. That high cost was Voyager's chief recommendation, for it would keep cash flowing through the Apollo political pipeline. Some second-level NASA managers doubted Voyager's technical feasibility. Most scientists disputed its merit. Only one American spacecraft had visited Mars, *Mariner 4* in 1964. Gambling everything on one big Voyager in 1973, NASA wanted to pass up opportunities to launch smaller missions in 1966, 1969, and 1971. NASA had gotten the mission backwards. James Van Allen, chairman of the space science board of the National Academy of Sciences, expressed his panel's opposition in colorful, if sexist, language: we should send "a number of well-equipped scouting parties to the several planets before we send out the wagon train with all of our women and children and a full set of household furnishings." Lacking a make-believe Mars race but facing a real war, NASA could not sell Voyager to Congress.

V

Until now science had been tailored to technology. With the demise of Voyager, it was possible to make technology serve science. When the future of the space agency was being debated in the late 1960's, physicist Ralph E. Lapp proposed a scientifically oriented space program with a budget of $1.5

billion to $2 billion per year. The planetary program that actually emerged, at first under the shadow of the manned side and then on its own in the 1970's, stands as a model of how the space program might be conducted.

The highlights of this program were the planetary missions run by the Jet Propulsion Laboratory, starting with the United States' first successful planetary mission, the Mariner flight to Venus in 1962. JPL launched seven successful *Mariners,* which were designed to make flybys of planets—two to Venus, four to Mars, and one which used a dramatic gravity-assist technique to visit Venus and then Mercury three times. In 1976 the Viking orbiter-lander, much smaller than that proposed for Voyager, carried the eagerly awaited life-detection experiments to the Martian surface. And in 1981 a completely reoriented and scaled down *Voyager* sailed beyond the terrestrial planets to Jupiter and Saturn and then headed for a rendezvous with Uranus in 1986. These missions were augmented by the small Pioneer missions, which made preliminary reconnaissance visits to the planets.

The planetary missions were relatively inexpensive. The *Mariners* actually declined in cost, despite the stiff inflation of the late 1960's and early 1970's. The 1969 *Mariner* cost $127 million, *Mariner* 1971, $133.5 million, but *Mariner* 1973, $98 million. With the *Mariners,* NASA first imposed cost as a discipline. Previously, two senior officials noted, NASA "stressed technical performance and schedule requirements over cost as a discipline." This was, of course, an indirect admission that NASA had been willing to pay pretty much whatever it cost in order to attain high technical standards under tight schedules. *Mariners* had the advantage of being evolutionary; these spacecraft were for the most part developed in sequence instead of concurrently, as in the Apollo program. Each mission also made greater use of designs from previous missions, which greatly reduced costs. Even Viking, which posed new problems because it had both

an orbiter and a lander equipped for complex biological experiments, cost less than $1 billion, despite inflation.

Still, with a relatively small expenditure of money, the planetary program made possible an intellectual revolution in our understanding of the solar system. The planets were realms of mystery before the space age. Now many of the surface and atmospheric features are well known: the multihued rings of Saturn, the volcanoes of Io, turbulent Jupiter, the red deserts of Mars, and the furious temperatures and intense atmospheric pressure which make Venus a "hellhole of a planet."

But perhaps the greatest legacy of the planetary explorations was a more subtle one—a gradually shifting view of the theory of the origins of the planets "from a cold birth to a hot one." Older notions held that the planets had accumulated while cold and that they were homogeneous, becoming differentiated later. Now it is believed that the planets accumulated while hot and that their differentiation occurred during the accretion period. Moreover, Earth's geological history, once studied in isolation, now stands in a new relationship with the other planets of the inner solar system. As scientists Bruce Murray, Michael Malin, and Ronald Greely said: "New insights are developing that link the Earth, including the very atoms that compose its sentient beings, with the origin and evolution of those other four planets . . . in a common planetary environmental history." This intellectual revolution represented the most profound achievement of the space program and provided its most cogent rationale.

This model of NASA—devoted to scientific and planetary missions plus some traditional activities such as aircraft research—probably could have maintained its balanced, relatively low-budget program for some time. The agency's appropriations totaled about $3 billion in the early 1970's, compared to almost $6 billion in fiscal year 1966, the peak of Apollo funding. But NASA, and the depression-ridden aerospace industry, sought a return to large-scale projects. Thom-

as O. Paine, NASA administrator from 1968 to 1970, wanted to "swashbuckle," as he put it to his intimates. NASA faced, though, a crisis of legitimacy with Congress and with Nixon's budget bureau, and Paine's grandiose plans got nowhere.

Paine's successor, James C. Fletcher, who headed NASA from 1971 to 1977, found the key to rebuilding his budget and reinvigorating the alliance with industry and the military through the space shuttle. Besides keeping alive the glamour of man in space, the shuttle was sold on the grounds of economy and practicality. The shuttle was supposed to be economical because it is a reusable vehicle. Its practicality came from its multipurpose nature: not only scientific and military missions could use it but commercial ventures as well for such activities as manufacturing precision objects in the more favorable environment of space. The shuttle's success was contingent on an economical, relatively trouble-free development.

Just the opposite occurred. Its development took longer and cost much more than anticipated; the number of missions that appeared to be feasible declined. The shuttle's turn-around time was slower than anticipated. Whipsawed between high development costs and reduced future prospects, the shuttle is falling far short of its original projections for commercial and scientific use. In their stead military domination looms.

The price for the shuttle was more than money. "NASA mortgaged nearly everything—science, space exploration, the development of new technologies—to build the space shuttle on what was a shoestring budget, as big Government projects go," said John Noble Wilford, the *New York Times* science writer. The planetary budget, adjusted for inflation, was slashed by a factor of four from 1974, when Viking expenditures topped out, to 1977. From then through 1982 the planetary slice floated between $200 million and $300 million annually (in 1982 dollars). That sum had to carry all the planetary activities, including Voyager, the Pioneer Venus mission, Galileo development, and the Deep Space

Network. There were no scraps for new missions. Faced with the Reagan budget cuts of 1981 and 1982, NASA chose what Wilford termed "bureaucratic triage." It saved the shuttle "by killing off most other projects." *Columbia* rose into orbit "from the ruins of the nation's civilian space program."

Some NASA officials argued, to be sure, that the shuttle would eventually benefit planetary exploration. But William Pickering, like most people involved in space science, was dubious. He preferred launching from "a good, solid launching site in Florida" to blasting off from "a moving platform in space." So long as spacecraft continue to weigh about a ton, existing technology is adequate to reach even the comets and asteroids, whose "primitive, undisturbed material" possesses great importance for understanding not only the origins of the solar system but all stars. As JPL scientist Arden Albee put it: planetary science's coexistence with the shuttle is like "being in a lifeboat with an elephant."

Planetary exploration and space science generally face a decade of tenuous existence as the militarization of the American space program gathers force. The emerging space program of the 1980's contrasts sharply with the program's first quarter century. During this classical era, exploration and scientific inquiry predominated over military considerations. Space became a new peaceful theater of intellectual experience as man gained a sense of unity with the solar system in which he lives. But space, once touted as an escape from or sublimation of Earth's quarrels, now looms as an extension of terrestrial hatreds. As 1984 begins, choices are being made that threaten to open a dangerous, expensive, and new phase of the arms race in the once peaceful vastness of space.

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Space Weapons Policy

He Who Decides a Case Without Hearing the Other Side . . . Tho He Decide Justly, Cannot Be Considered Just—SENECA

FOREWORD=

MILITARY USAGE HAS LONG BEEN a feature of U.S. space policy. Although the civilian and military space programs are administered separately, there are inherent technological inter-relationships. Launch rockets, for example, boost both civilian satellites and ICBMs.

A vast array of small orbiting communications satellites are launched routinely. Some of these form an integral part of both U.S. and Soviet defense structures. They range from devices for communications with land, sea and air forces to those for the monitoring and verifications of arms control agreements. The satellites are both vital and vulnerable.

The Soviet development of an operational antisatellite (ASAT) capability has led to a U.S. policy that military space systems "be designed, developed and operated to enhance the survivability and endurance of critical mission functions." Since 1977 this policy has included the development of a non-nuclear ASAT capability "to deter threats to space systems of the United States and its allies and threats from space systems supporting hostile military forces."

The U.S. ASAT program has become one of the principal elements in the current controversy over U.S. space weapon policy. The program has technological features which are subject to dispute as to feasibility and cost. The ASAT weapons system also relates to existing treaties concerning space weapons, arms control, and nuclear war prevention.

A series of talks with the Soviet Union on ASAT weaponry, held during the Carter administration, was cancelled following the invasion of Afghanistan. Opponents of U.S. deployment of ASAT weapons take the position that the program should be restrained pending resumption of U.S.-Soviet negotiations, to avoid an "arms race in space."

Proponents take the view that the Soviets have long had an ASAT capability which the U.S. must have also.

Another program that has become a major element of the current controversy over space weaponry involves a system intended to knock down attacking nuclear missiles while in flight. Antiballistic missile weaponry not only has its own technological features, controversial as to cost and feasibility, but its own relationship to treaties and nuclear war prevention strategy.

For some two decades the principle of "mutual assured destruction" has been a feature of U.S. nuclear war deterent policy. This holds that so long as the Soviet Union and the United States each has the capability to destroy each others' population centers neither will do so. Another policy facet involves "theater nuclear forces." Their purpose in Europe has been not just to avoid nuclear war, but to deter any conventional war that might become nuclear. Unable to determine the general geographic location of where or how NATO could defeat the Soviet army with conventional forces, theater nuclear weapons have long been deemed essential by NATO.

The antiballistic missile defense concept would, its proponents maintain, add a new strategy dimension by mitigating the damage potential of Soviet nuclear weapons. Opponents believe that such an ABM system would be destabilizing, in that it would shift the "balance of terror" by denying in whole, or part, the Soviet ability to strike the United States, thus accelerating the arms race, and rendering obsolescent existing arms control concepts.

Complicating policy decisions on space weaponry, as well as strategic, theater, and arms control concepts, are constantly emerging technological factors, such as lasers and others which play an obscure but vital role in weapons systems.

The Congress in reaching such decisions must contend with a complex technology, much of which is being developed outside the military but has a scientific impact upon it.

Current U.S. Space Policy

DIVISION OF THE U.S. SPACE PROGRAM into separate military and civilian components was established by President Eisenhower.

NASA

The National Aeronautics and Space Act of 1958 created the National Aeronautics and Space Administration (NASA) to conduct civilian space activities. It assigned military space programs to the Department of Defense (DOD).

Reagan Policy

On July 4, 1982, President Reagan released his administration's space policy for both military and civilian programs. One goal called for the strengthening of U.S. security. The new policy directive stated that "survivability of space systems will be pursued commensurate with the threat, with the planned use in crisis and conflict, and with the availability of other assets to perform the mission"; and the United States will develop an antisatellite (ASAT) system both to deter threats and, "within such limits imposed by international law, to deny any adversary the use of space-based systems that provide support to hostile military forces." The President stated that military and civilian programs will continue to be separate entities. He outlined guidelines for cooperation between the two.

In August 1982, DOD released a Fact Sheet outlining a new defense space policy. DOD and NASA will continue to cooperate under existing agreements on the terms of the President's space policy message. DOD recognizes the Space Shuttle as the country's primary launch system "and the need for the DOD to continue to cooperate with NASA efforts to develop a fully operational Space Transportation System."

Regarding weapons in space, the Fact Sheet stated that the development of an ASAT capability will continue "within such limits imposed by international law" and added that DOD planning "emphasizes adherence to the existing international legal regime which pertains to space" and that DOD will "consider verifiable and equitable arms control measures that would ban or otherwise be compatible with United States national security." The new policy contains "no new directions in space weaponry," but provides support for continued research.

Missile Defense System

In a televised address to the Nation on defense policy on March 23, 1983, President Reagan stated in part:

"Up until now we have increasingly based our strategy of deterrence upon the threat of retaliation. But what if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack; that we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies?

"I know this is a formidable technical task, one that may not be accomplished before the end of this century. Yet, current technology has attained a level of sophistication where it is reasonable for us to begin this effort. It will take years, probably decades, of effort on many fronts. There will be failures and setbacks just as there will be successes and breakthroughs. And as we proceed we must remain constant in preserving the nuclear deterrent and maintaining a solid capability for flexible response. But is it not worth every investment necessary to free the world from the threat of nuclear war? We know it is!"

Reagan on ASAT

The Reagan Administration established an Intergovernmental Group to review and study ASAT policy.

President Reagan reaffirmed the U.S. commitment to pursue an operational ASAT system. His July 4, 1982, statement further emphasized U.S. space policy commitment to the ASAT program "with operational deployment as a goal."

The policy statement identified the primary purpose of the ASAT system as deterring threats to space systems and denying "any adversary the use of space-based systems that provide support to hostile military forces."

In August 1982, the Defense Department further released an unclassified fact sheet outlining space policy. The policy directs the continued development of an ASAT "within such limits imposed by international law," adding that DOD planning emphasizes "adherence to the existing international legal regime which pertains to space" and that DOD would "consider verifiable and equitable arms control measures that would ban or otherwise limit the deployment of specific weapons systems should those measures be compatible with United States national security."

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Treaties Involved

A NUMBER OF TREATIES currently affect international military activities in space.

Both the Limited Test Ban Treaty of 1963 and U.N. Outer Space Treaty of 1967 forbid the placing of nuclear weapons in space. In 1972, the Treaty on the Limitation of Anti-Ballistic Missile Systems prohibited interference with "national technical means of verification," referring to reconnaissance satellites. The ABM accord also prohibits development, testing or deployment of space-based Anti-Ballistic Missile systems. Although systems based "on other physical principles" are open to further discussions.

Carter Limitation Talks

President Carter announced during a press conference on March 9, 1977, that he had consulted the Soviet Union about arming satellite bodies and also "to forego the opportunity to destroy observation satellites." Three rounds of ASAT limitation talks were then held but the Soviet invasion of Afghanistan in December 1979 chilled arms control talks.

The United States wanted the discussions to include a treaty to stop ASAT tests. A major U.S. objective was the dismantling of the Soviet Union's ASAT system and to provide for verification.

Soviet Treaty Proposals

On August 11, 1981, the Soviet Union submitted to the United Nations a draft treaty, calling for a ban on the stationing of weapons in space. It was referred to the Committee on Disarmament. No action was taken.

Nine U.S. Senators visiting Moscow met with Soviet Premier Andropov on August 18, 1983. The Premier expressed concern about space weapons. He urged a "complete prohibition of the testing and development of any space-based weapons for hitting targets on Earth, in the air or in outer space." Premier Andropov committed the Soviet Union "not to be the first to put into outer space any type of anti-satellite weapons," as long as other nations "refrain from stationing in outer space antisatellite weapons of any type." Although he did not admit that the U.S.S.R. possesses an ASAT system, he did appear willing to suspend its testing and discuss possible dismantlement, in exchange for American commitments not to station similar weapons in outer space.

A revised Soviet draft U.N. treaty was introduced on August 22, 1983. This differed substantially from their 1981 proposal. The new treaty placed a ban on the use of force in outer space. It also called for dismantlement of all existing ASAT systems, though the Soviet Union denies it has developed such a system. Other provisions prohibit the use of manned spacecraft for military purposes or to launch military satellites. It was referred to the U.N. First Committee and from there to the Committee on Disarmament. On November 25, 1983, the United States was the only nation in the First Committee to vote against a resolution urging negotiations on a treaty to ban space weapons. The vote was 120-1. Only the United Kingdom abstained. The U.S. said it was "not ready to negotiate at this time."

Verification Concerns

Verification is said to be the biggest obstacle to an ASAT accord. The difficulty is over exactly what draft treaties might prohibit: development, testing, possession, deployment, or use; or demands, such as the dismantlement of existing systems. Only the Soviet co-orbital system is presently considered operational. It is likely to become the cornerstone for any future ASAT treaty discussions. In the case of the U.S. F-15 ASAT, the Soviet Union would have difficulty in verifying development and testing, particularly since the American system is small and can be placed on any F-15. While the Soviet ASAT can be launched from only two available launch sites and requires large and relatively easily detectable rockets.

Use of an ASAT system is not always easy to detect. Problems could arise if the Soviets perfect a single-orbit interceptor. Since distinguishing between a malfunctioning satellite, one hit by space debris, or a satellite attacked by an ASAT is extremely difficult.

Verification difficulties could also be encountered if testing is not banned. For example, the SS-9 is used to launch Soviet ASATs and for launches of radar-ocean reconnaissance and electronic-ocean reconnaissance satellites. U.S. ability to verify a payload on an SS-9 is classified. Some measures to assure that an ASAT is not being carried by an SS-9 will have to be made.

Still other difficulties might arise if changes are made to Soviet ASAT test patterns.

Assurances that existing systems will be dismantled and

(Continued on page 96)

Space Weapons Systems

THE PRINCIPAL SPACE WEAPONS SYSTEMS involve antisatellite and ballistic missile defense capabilities.

ASAT

The term "antisatellite" or ASAT, refers to a weapon system used to destroy Earth-orbiting satellites.

Devices can be ground-based, placed on airplanes, or used in outer space. Both ground- and air-based weapon systems include:

(1) direct launchings of missiles carrying nuclear or nonnuclear warheads;

(2) co-orbiting devices with explosive warheads; or

(3) a direct-energy (laser) weapon.

Conventional Weapons

Non-nuclear ASAT systems involve explosive devices or impact vehicles. Here an "interceptor" would maneuver close to its target so that exploding shrapnel from the interceptor would destroy the target. According to one plan, an interceptor could be launched to attack an enemy satellite at a specified time. Or it could be launched into orbit to be activated when needed (known as a "space mine"). Impact vehicles require accurate targeting mechanisms to crash the interceptor directly into the enemy satellite.

Nuclear Devices

Nuclear warheads have a large "kill radius," which is an advantage over conventional weapons. They do not require highly accurate targeting systems. Their disadvantage is that the "kill radius" can affect both friendly and enemy satellites.

Nuclear weapons in space are strictly prohibited by international treaty. The United States did have a nuclear warhead ASAT capability from approximately 1963 to 1975. Western observers believe that the U.S.S.R. has maintained a similar capability since the early 1960's.

Laser and Particle Beams

High-energy directed-weapons, such as lasers and particle-beams, require accurate targeting mechanisms. Research is being conducted in the U.S. and Soviet Union.

The U.S.S.R. is believed to have an operational ground-based laser ASAT system. The United States has conducted several airborne tests of a laser system. Some experts believe that technology for an ASAT system will have to wait until some date in the distant future.

The U.S. Department of Defense states: "Lasers can be used to 'blind' the sensors on a satellite, or if sufficient power is available, to destroy [illegible] satellite through heating.

"Particle-beams (charged or neutral atomic particles—electrons, protons, or neutrons) could destroy a satellite through heating or by disrupting its electronics.

"A major advantage of directed-energy weapons is that their destructive energy travels at the speed of light, denying the target sufficient time for any possible evasive maneuvers. Also, several targets could be engaged consecutively in very short periods of time.

"The major disadvantage is that the systems require great amounts of energy and large associated structures, making them difficult and expensive to construct in space and vulnerable to attack.

"The alternative, basing laser systems on Earth and aiming them up into space, presents difficulties because the Earth's atmosphere tends to disperse the beam, and only a small fraction of energy reaches the target. For particle beam weapons, Earth-basing would present the possibility of the path being deflected by the Earth's magnetic lines."

Tests

Atmospheric testing of laser weapons has occurred. Supporters maintain that space-based ASAT lasers could become available this decade. Critics argue it will take 20-30 years. Particle-beam technology is further behind laser weapon research. Directed-energy weapons could be used for ballistic missile defense.

Ground-based Systems

During the 1960's, ground-based ASAT systems were studied by the United States. An operational system was developed by the U.S. Army using NIKE-ZEUS missiles at Kwajalein Atoll in the Pacific. Tests were conducted from May 1963 until deactivated in 1964. The Air Force tested a system using THOR missiles on Johnston Island, also in the Pacific. Beginning in May 1964, it remained operational until 1975.

Soviet Union

The Soviet Union appears to have several different ASAT systems. A ground-based co-orbital system is "operational" according to the Defense Department. Rumors of a

direct-ascent nuclear ASAT or ground-based laser have not been confirmed. Soviet Premier Nikita Khruschev told American reporters on July 16, 1962, that the Soviet Union could "hit a fly in outer space." This was interpreted to indicate that the Soviets had an ASAT capability using nuclear warheads on GALOSH missiles at the Shagan facility and around Moscow. Such an ASAT system remains unconfirmed.

Soviet Co-orbital

The most favored Soviet ASAT system appears to be a ground-based, explosive ASAT device. An interceptor would be launched by a SCARP launch vehicle (similar to the SS-9).

It is believed that the Soviet Union has conducted some 20 tests of their ASAT system. Exactly how successful the Soviets have been is said to be difficult to determine.

Air-based Systems

The Defense Department is developing a Miniature Homing Vehicle (MHV) which could be launched from a two-stage rocket or carried by an F-15 aircraft. Using sensors, the MHV would locate, track and destroy the target satellite by impact force.

Range of the MHV-ASAT is classified. But Soviet reconnaissance, weather and navigation satellites are believed to be within range. The Soviet Salyut space station and manned and unmanned-resupply vehicles are also within range.

Pentagon experts note that U.S. ASAT systems are more flexible than those being developed by the Soviet Union, since F-15's could be based anywhere in the world. ASAT-carrying F-15's based in the southern hemisphere would make Soviet early-warning and communications satellites vulnerable. Prime targets for U.S. ASAT systems reportedly might include Soviet nuclear reactor-powered ocean reconnaissance satellites. Dr. Robert Cooper, director of the Defense Advanced Research Projects Agency (DARPA) stated in April 1982 that 15 "aircraft would be equipped for the ASAT role." A year later, he stated that six "captive tests of the ASAT had been successfully completed."

Test Launch

A successful launch of an air-based ASAT launched from an F-15 took place in January 1984.

On January 27, 1983, the General Accounting Office (GAO) issued a report on the U.S. ASAT program. GAO said the air-launched ASAT system was selected as a quick and cheap form of ASAT capability, but it has become "a more complex and expensive task than originally envisioned, potentially costing in the tens of billions of dollars." GAO recommended Congress review the program and consider possible alternatives before the vehicle enters production.

Conventional Space-based Systems

From 1960 to 1962, the United States had a program to develop a satellite capable of rendezvous with enemy satellites in earth-orbit. Called SAINT, this project never reached the flight-testing stage.

Little is known about Soviet programs in this area.

Space Shuttle as ASAT

The U.S.S.R. has told the United States it considers the Space Shuttle an ASAT-related vehicle, based on the fact that the shuttle can maneuver close to satellites. The shuttle's Remote Manipulator System (RMS) can be used both to deploy and retrieve satellites in orbit. The Soviets contend the RMS could attach destructive devices to satellites.

The Space Shuttle will test systems having an ASAT application. It could also carry components of space-based weapons into orbit. The National Aeronautics and Space Administration denies that the Space Shuttle is a weapon.

The United States has expressed concern about potential Soviet attack on the Space Shuttle. The Defense Department has raised the possibility of equipping the shuttle with defense laser systems. The Soviets have countered that this would positively make the Space Shuttle an offensive weapon.

Space-based Ballistic Missile Defense

Similar technologies could also be applied to destroy ballistic missiles enroute to their targets. Intercontinental Ballistic Missiles (ICBMs) and Submarine-Launched Ballistic Missiles (SLBMs) must "arc" through space to reach their targets. A space-based defense system could be developed to destroy these missiles before separation of individual warheads.

A group called High Frontier prepared such a plan in 1982, proposing a Global Ballistic Missile Defense System. It recommended placing 432 satellites into Earth-orbit, each armed with 40-50 Miniature Homing Vehicles based on the design for the F-15 ASAT system. The group stated that a space-based BMD system could be established with existing technology.

Laser or particle beams could also be used for space-based ballistic missile defense, according to some analysts.

Particle-beams and Lasers

Currently, the United States is developing the necessary technology for a space-based laser weapons system. This system could have ASAT applications.

The U.S. Air Force has tested an "airborne gas dynamic laser" for use against tactical missiles. As noted by Air Force Secretary Hans Mark in 1981, "These efforts will lead naturally to the solution of problems that will be faced when we are ready to put high-energy lasers in space."

The Defense Advanced Research Projects Agency (DARPA) has been developing a space-based laser technology program "which involves three technologies and is referred to as the 'space-laser triad.' The first technology, for acquisition, pointing and tracking of the target, is code-named TALON GOLD; it will be tested in 1985 aboard the Space Shuttle as part of the Air Force Space Test Program. The TALON GOLD experiment will test a low-power laser against both high-altitude aircraft and space targets. The second technology area, high efficiency infrared chemical lasers, is being developed under the name PROJECT ALPHA; it is a ground-test program to establish the feasibility of a laser suitable for use in space. Chemical lasers are considered better than gas dynamic lasers for space purposes because they are smaller, require low temperatures and a vacuum (the conditions in space), for operation and the toxic wastes would not present a disposal problem. ALPHA was originally designed to produce 5 megawatts of power, but recent developments may enable doubling that power level. New advances in short wavelength lasers may show that these would be preferable to chemical long-wavelength lasers. The third technology, mirror and beam control optics, is being studied under the name LODE (Large Optics Demonstration Experiment). It is designed to establish the feasibility of large aperture beam control in space." Funding for DARPA's high-energy laser program was $129 million in FY83. The FY84 request is $172.6 million.

ASAT Funding

The individual armed services have also developed their own high-energy laser programs. Together with DARPA, they have spent nearly $2 billion on research. Particle-beam research in the United States began in 1958. Then called SEESAW, it was terminated in 1972 by DARPA. In 1974, the Navy Department established CHAIR HERITAGE, its own particle-beam program. It was later transferred to DARPA in 1979.

A little over a year later, in 1980, the Army's particle-beam program, called WHITE HORSE, also became a part of DARPA.

During consideration of the FY83 request, debate emerged over whether to continue existing research programs for developing chemical lasers or proceed with short wavelength laser technology. The FY83 DOD funding bill added $20 million for short wavelength laser technology, as opposed to high-energy laser research in general. It funded $173 million for DARPA and $36 million for the Air Force.

A new Strategic Laser Systems Technology Program was created by the Department of Defense Appropriations Bill. $28 million was provided for space-based laser research. DARPA's Strategic Technology Program of $280.5 million and the Advanced Radiation Technology Program of $52.53 million also received funding.

Estimates on when the United States might be able to launch an operational space-based laser range from 6 to 30 years.

Soviet Laser and Particle-beam Research

For years, experts have speculated that the Soviet Union is developing space-based particle-beam and laser weapons. During congressional hearings in March 1982 portions of a Defense Department classified report on Soviet laser efforts were inadvertently read into the record. That report suggested that the U.S.S.R. would be capable of launching a space-based laser into earth orbit in 1983. Dr. Richard DeLauer, Undersecretary for Research and Engineering, later stated that 1983 was "the bottom range of possibilities" which the Defense Department considered likely. Dr. DeLauer stated that he believed "the Soviets have about a five-year lead in space-based laser technology over the United States, and that since we could place such a weapon in orbit in possibly ten years, then the Soviets may do so five years from now."

He said, "Over the past ten years, the Soviets are also estimated to have taken the lead in the development of directed energy weapons such as high-power lasers and possibly radio frequency devices. They have devoted substantial resources in these areas, and the fact that they are developing very high-power microwave generation also gives rise to suspicions of possible weapon intent. For example, their high energy laser program is three-to-five times that of the U.S. level of effort, and tailored to development of specific laser weapon systems (as opposed to the U.S. work which is largely exploratory). Available information suggests that the Soviet weapon effort is by far the world's largest, and possibly could lead to a demonstrated capability in a wide variety of ground, ship and aerospace application during the latter half of this decade.

"Finally, Soviet spacecraft perform more than a dozen specific military functions, several of which are directly associated with weapon systems. In fact, we believe their space station program engages in military activities and may be the forerunner of a weapons platform. In sum, based on the evidence available to us, it is clear that the Soviets have a massive military space program."

Action in the Current Congress

CONGRESSIONAL INTEREST IN SPACE WEAPONS has risen considerably in the current Congress. One resolution has been reported from committee in the Senate and two are pending in the House. Both call for a resumption of the ASAT limitation talks with the Soviets. One House and one Senate resolution would promote international cooperation in space as an alternative to a space arms race. Conversely, one Senate resolution, one Senate bill and one House bill would accelerate U.S. space weapons programs. Five sets of hearings have been held specifically on this topic. In addition, two amendments were debated on the House floor and two on the Senate floor during consideration of the FY84 DOD Authorization Bill relating to space weapons. Language was added to DOD appropriations bills as well.

Opposition to Space Weapons

Two resolutions in the House are H.J.Res. 87, introduced by Representative Robert W. Kastenmeier, Wisc., Dem., on January 25, 1983; and H.J.Res. 120, introduced by Representative Moakley and 76 co-sponsors on February 2, 1983. The two resolutions are very similar. They call on the President to resume talks with the Soviet Union aimed at banning all weapons from space. The Moakley resolution directs the President to request the United Nations to initiate negotiations aimed at expanding Article IV of the 1967 Outer Space Treaty to include such a ban. Hearings were held by the House Foreign Affairs Committee on November 10, 1983.

In the Senate, S.J.Res. 28 was introduced by Senator Paul E. Tsongas, Mass., Dem., and two co-sponsors on February 3, identical to Rep. Moakley's resolution. On February 2, Senator Pressler and 6 co-sponsors introduced S.Res. 43 calling for negotiations to ban antisatellite weapons as a first step towards banning all weapons from space. Following hearings on April 14 and May 18, 1983, Senators Pressler and Tsongas and others introduced a compromise resolution. S.J.Res. 129 was favorably reported by the Senate Foreign Relations Committee on November 18, 1983.

Senator Matsunaga introduced S.Con.Res. 16 on March 10, 1983. This expressed the sense of the Senate that the President renew the space cooperation agreement with the Soviet Union and explore opportunities for cooperation in space as an alternative to an arms race in space. A similar resolution, H.Con.Res. 140, was introduced by Representative Mel Levine, Calif., Dem., and 6 co-sponsors on June 30, 1983.

Support for Space Weapons

On March 24, 1983, Senators Malcolm Wallop, Wyo., Rep., and Paul Laxalt, Nev., Rep., introduced S.Res. 100, calling for the President to request funding to establish a space-based ballistic missile defense system as soon as possible. The resolution was referred to the Armed Services Committee.

On May 19, 1983, Representative Ken Kramer, Colo., Rep., and 11 co-sponsors introduced H.R. 3073, the People Protection Act. The bill would establish a new agency for accelerating the development of directed-energy technology. It was referred jointly to the Committee on Armed Services, Foreign Affairs, and Science and Technology. Hearings were held by the House Armed Services Committee on November 10. Senator William L. Armstrong, Colo., Rep., introduced S. 2021, an identical bill on October 28.

In addition to the two House hearings noted above, the Senate Foreign Relations Committee held hearings on space weapons and on the President's March 23 speech on April 14 and May 19. The Senate Armed Services Committee held one day of hearings on May 2.

Floor Debate

During House consideration of the FY 84 DOD Authorization Bill, H.R. 2969, Representative George E. Brown, Jr., Calif., Dem., tried to deny procurement funding of $19.4 million for the U.S. ASAT system. Research and development funding would not have been affected. The amendment was debated on May 26 and June 14. It was defeated by a vote of 243-177. On July 21, Representative John F. Seiberling, Ohio, Dem., introduced an amendment to prohibit flight tests of the U.S. ASAT until authorized by Congress. The amendment was defeated 275-142.

In the Senate, on July 18 an amendment introduced by Senator Tsongas was adopted by a vote of 91-0. This provided that no funding be used to test any explosive or inert ASAT against objects in space unless the President certified to Congress that (1) "the U.S. is endeavoring in good faith to negotiate a treaty with the Soviet Union for a mutual and

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PRO

Are Administration Initiatives Sound

by Hon. John W. Warner
United States Senator, Virginia, Republican

From an address delivered on the floor of the U.S. Senate on March 24, 1983. Sen. Warner is a member of Senate Committees on Armed Services, Energy & Natural Resources, and Rules & Administration.

PRESIDENT REAGAN ANNOUNCED a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles. This program would capitalize on our technological capacity to develop means by which we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies.

"The potential contribution of directed energy weapons is significant."

The Senate, over the past 3 years, has been taking increased interest in this area. The initiatives of the President will be received and studied with great interest.

The potential contribution of directed energy weapons is significant. For example, they could deny the use of space for collecting and distributing crisis management and targeting information while protecting our space assets that warn against a surprise attack; engage and defeat limited nuclear strikes using ballistic missiles by engaging such missiles in the vulnerable boost phase; provide response options that neutralize or disrupt enemy targets in a measured, selective manner without breaking the nuclear threshold; selectively thin out the attacking missiles and aircraft and disrupt any attempt at a disarming first strike; aid U.S. strategic force retaliatory strikes by suppressing air defenses; and continually attrit reserve strategic forces in a nuclear war and deny targeting information essential to the effective use of such forces.

Directed energy weapons might be used as a stand-alone defense, or more likely, as part of a defense-in-depth concept. Second, considerable research and development is underway on laser and particle beam-related systems with potential for defensive weaponry.

"Laser beams, particularly the chemical laser, will likely be the first deployable beam weapons developed."

Laser beams, particularly the chemical laser, will likely be the first deployable beam weapons developed. A laser is a beam of very intense, single wavelength electromagnetic waves, either of light or high energy X-rays. Such a weapon can be focused very precisely because either the light or X-ray wavelengths all have the same frequency and phase. The five different types of lasers, which can be applied to fusion energy as well as beam weapons, are all being researched at U.S. laboratories.

The chemical laser, which could be developed for military deployment, uses a gaseous medium in which a chemical reaction is induced. The product of the reaction emits laser light.

The gas laser, a burning gas such as a hydrogen and flourine mixture, is suddenly compressed, and the energy distribution that results from the compression is then stimulated to emit single-frequency light waves at very high energy.

An electron discharge laser uses replaceable energy from an electron beam to create the source of laser light. Such a laser would be very efficient for use in space

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Space Weapons National Policy?

CON

by Hon. Larry Pressler
United States Senator, South Dakota, Republican

From addresses delivered on the floor of the U.S. Senate on February 17 and April 7, 1983. Sen. Pressler's committee assignments include chairmanship of the Subcommittee on Arms Control of the Senate Committee on Foreign Relations.

WE, FAR MORE THAN THE SOVIETS, would be compromised by a space weapons race because we must, out of necessity, rely upon space-based systems for conducting many functions. The Soviets do have alternatives to space-based systems—alternatives that we do not possess. This is both a product of our open society and our particular geographic situation.

"We, far more than the Soviets, would be compromised by a space weapons race..."

I would like to address another aspect of this issue, and that is the very high cost of a space weapons race and its likely implications for the American taxpayer, who is already heavily burdened by the high cost of keeping America safe. Adding a space dimension to United States and Soviet weaponry is likely to add significantly to this burden. Moreover, we already face major deficiencies in the current constellation of air, land, and sea forces. Aircraft reportedly lack spare parts; we have insufficient ammunition for sustaining any potential lengthy conventional war in Europe; we do not have enough chemical warfare clothing for troops; the list is very long in this area. Given a new burden in the area of space weaponry, we cannot hope to make good on these deficiencies. Indeed, we are likely to exacerbate the problems and we will likely be spreading ourselves even more thinly.

It is for this reason that I support immediate resumption of ASAT talks. If we cannot ban space weaponry at this early stage in the competition, then I believe that it will be increasingly difficult, if not impossible, to avoid ever higher expenditures on space weaponry. We will be like the habitual gambler who has to continually double his bet to stay in the game. Once we enter this game, which is already very expensive even though it is still on the ground, it will be ever more difficult to find a way out.

"..let us consider the U.S. ASAT weapon ... With this money, we could do better things in defense and... serving American taxpayers."

First, let us consider the U.S. ASAT weapon which is soon to be tested and deployed. The current price tag for that system is $3.6 billion. This is already a sevenfold increase over the advertised cost when it was initiated several years ago. With this money, we could do better things in defense and in the area of serving American taxpayers.

That program has not received the close congressional scrutiny it deserves. We have here a system that, in dollar value alone, approaches the MX missile's advertised price tag. I believe that before we move toward testing and deployment of this ASAT system, which will join the F-15 aircraft to a rocket and a satellite interceptor, we must give it the same close examination that has attended the MX system. If we are to have any examination of the strategic implications of this ASAT, as well as its budgetary consequences, the Senate must act quickly, for once the system is tested our ability to influence this program will be very limited.

Beyond ASAT's, there are many additional concepts floating around the defense

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because its energy source is electricity, not an exhaustible chemical fuel.

Two other types of lasers, X-ray lasers and free-electron lasers, yet to be perfected technologically, have greater advantages of energy density and flexibility than those listed above. The X-ray laser has promise for long-range ballistic missile defense, based in space. The X-ray laser, which is just a single pulse, is by far the most energy-dense, delivering thousands of times more energy per pulse than conventional lasers. In addition, the target absorbs the X-rays very efficiently, making this weapon capable of very efficient destruction of missiles.

Particle beams also deliver energy in a highly controlled pulse traveling at near the speed of light. But instead of a pulse of intense electro-magnetic radiation, the particle beam consists of subatomic particles, electrons or protons, neutral atoms, usually hydrogen, or usually magnetized macroscopic particles accelerated to high speeds. A particle beam destroys its target, the triggering mechanism, by creating a very intense shock wave within the mechanism, like a very small, but extremely heavy and powerful hammer striking down on the target.

"The X-ray laser has promise for long-range ballistic missile defense, based in space."

Electron beams can be generated in the range of millions of volts. Scientists researching the electron beam for military or civilian energy use have discovered that the electron beam becomes a complex structure of electrons and a magnetic field. Such structured beams are capable of carrying higher currents and more energy for much longer distances at much greater levels of power output.

Proton beams, which have been researched intensively for the past 30 years, use an electron beam as a seed and then are accelerated in their own right. As protons are 2,000 times heavier than electrons, a proton beam of the same velocity has 2,000 times the energy of an electron beam.

Neutral particles eliminate many of the problems of charged-particle beams, which can degrade both the efficiency and controllability of the beam. U.S. researchers hope to produce a beam of protons at an energy of 2.5 million electron volts, capable of traveling at 99 percent of the speed of light.

Control and targeting of a macroscopic particle beam would be more difficult, but the unparalleled power density of the beam—due to the large mass of the particles—gives it considerable potential as a beam weapon.

"In addition, nonnuclear ballistic missile defense systems are being researched by the Army."

The Department of Defense is pursuing development efforts related to space-based, air-borne, and ground-based laser systems for antisatellite, antiaircraft and possibly antiballistic missile defense missions. Serious work is also being performed on particle beam weapon systems.

In addition, nonnuclear ballistic missile defense systems are being researched by the Army. Such systems could provide a capable point-defense of national assets in the 1990s.

The private sector has also offered proposals—largely drawing upon the technologies under development by the Department of Defense—intended to give the United States an enhanced strategic defense capability. One such proposal, called "High Frontier," would involve three components.

The first system would be a ground-based defense of missile silos that would consist of rapid-fire guns able to launch a cloud of projectiles and destroy incoming warheads before they reach their target.

The second system would be a global ballistic missile defense that would consist of 432 satellites, all hardened to minimize the effect of nuclear explosions outside

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community calling for lasers and particle beam weapons that could be based on Earth and aimed at satellites in orbit or, alternatively, based in space and targeted at other space systems. The cost of such systems is difficult to predict, for the simple reason that they require several as yet unattained major scientific and technological breakthroughs. However, we can safely say that the cost will greatly exceed the "tens of billions of dollars" that the GAO estimates for the current U.S. ASAT effort which is based upon off-the-shelf technology.

Beyond antisatellite platforms, there are concepts that call for space-based military fortresses which would attack several space systems at once or would provide for an anti-ballistic missile defense in the skies. The most prominent of these concepts to date is the High Frontier concept. High Frontier would be based, we are told, on current technology that would use conventional weapons to attack ballistic missiles in their boost phase. Let me note that this concept is prohibited by the 1972 ABM Treaty to which we and the Soviets are bound. At a minimum, High Frontier would require a renegotiation of that accord and at a maximum we might have to give up what many regard as the most useful arms control accord to date to deploy the High Frontier.

"Should we believe that it is in our security and budgetary interests to accept such a costly new arms race?"

But there is another important question that is raised by High Frontier. Can we afford it? While the proponents claim that it would cost only $40 billion—and that is an astronomical amount of taxpayer money—other estimates, including one offered recently by the Armed Forces Journal, put the price tag at between $200 and $300 billion. That amount rivals the annual U.S. defense budgets for the mid-1980's. Once we begin to talk about other more exotic concepts, that price tag will continue to increase.

Should we believe that it is in our security and budgetary interests to accept such a costly new arms race? Once it begins, it may be impossible to avoid these even more sophisticated and ever more costly weapons in space. Or should we examine the situation closely to consider the possibility that arms control may provide an alternative to such a space weapons race? I believe that we have no alternative to first giving arms control a try.

I agree with the President that the United States has fallen behind in some areas in the development of our military forces. The problem we face is as much a problem of sustainability—that is, the provision of spare parts, sufficient ammunition, pilot training, and such—as it is an issue of strategic forces modernization.

"... the proposed laser BMD would lead to both an increased tax burden and reduced spending in other military areas."

I commend the President for keeping the U.S. laser program option open. Concerning the ground and space deployment alternatives, in the view of many specialists these weapons will be space based. There may be too many problems to overcome in operating a laser through Earth's atmosphere. Laser energy is dispersed and laser beams bend under atmospheric conditions. Moreover, if we are to provide our allies with the protection of a laser-ballistic missile defense (BMD) system, space basing seems the better approach.

Let me note the more obvious problems with a space-based BMD system. At the top of the list are the budgetary and strategic implications of such a weapons program.

Costs would have to come from somewhere and, as I see it, the proposed laser BMD would lead to both an increased tax burden and reduced spending in other military areas. We would not be in a position to modernize and correct existing

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the Earth's atmosphere. These satellites would be constantly orbiting at about 300 miles altitude, each armed with 40 to 50 intercept devices similar to the air-to-air missiles now carried by U.S. fighter aircraft.

The third system would be a second generation global ballistic missile defense whose specific configuration would depend upon the rate of technological advance. It might simply be an upgrading of GBMD-I, or, depending on the solution to problems of directed-energy beam weaponry, could be an entirely new system.

"..the President is correct in his recognition of the potential offered by American technology for our national security."

Uncertainties exist about the cost, technical feasibility and arms control implications of each of these approaches.

Just as important as the technical capabilities of these approaches are the provisions and goals of existing and future arms control treaties. I can not emphasize too strongly the need to coordinate the technical development of these weapons within the framework of the existing arms control agreements and the future agreements the world hopes and prays for.

I believe that the President is correct in his recognition of the potential offered by American technology for our national security. His assessment that, "years, probably decades, of effort on many fronts is required" is also correct. I believe that his call for increased attention to our technological capability will lend an impetus that may provide positive dividends. The precaution and responsibility that we have is not to raise hopes and expectations too early.

by Hon. Howell Heflin

United States Senator, Alabama, Democrat

From an address delivered on the floor of the U.S. Senate on April 27, 1983. Sen. Heflin in a member of Senate Committees on Agriculture, Nutrition & Forestry; Commerce, Science & Transportation; and the Judiciary; as well as the Select Committee on Ethics.

I SINCERELY BELIEVE THAT AN OBJECTIVE EXAMINATION of President Reagan's recent call for the development of strategic defense systems will disclose that this is a concept whose time has come.

Once past the emotional reactions of those who are tied to the strategic doctrines of the past, this new approach may, indeed, lead to an ultimate reduction in offensive missiles on both sides.

"For too long we have relied on strategic policy based on the threat of retaliation rather than a commitment to self-defense."

For too long we have relied on strategic policy based on the threat of retaliation rather than a commitment to self-defense. I have wondered ever since the signing of the ABM treaty in 1972, what could be more stabilizing than the ability to defend one's homeland against nuclear attack?

Yet, many of those who are most vocal through the media continue to insist that defense would touch off a new arms race by raising fears that one side was preparing to attack and then defend itself against retaliatory attack. Defense, in fact, is not provocative—it is the opposite. If each side neutralizes the other's offensive capability, the threat of aggression must be reduced. The U.S. history discloses proudly that ours is not an aggressor nation. But several times, we have been caught, with almost

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deficiencies in our current conventional and strategic forces. We are, therefore, likely to be spending more and be doing more militarily, but we are also likely to be doing many things badly rather than a few things well.

Strategically, there would be little to gain from such a space-based BMD system. As the President rightly noted, should we end up adding lasers to the U.S. weapons posture it could be "viewed as fostering an aggressive policy." I might add, this policy could be highly destabilizing. One possible course of action would require that we combine the strategy of building a BMD system together with negotiating very significant arms reductions in strategic forces. There is irony in this situation. If we can reduce our strategic forces to a point where a BMD system would no longer appear "aggressive," then we would also greatly reduce the need for a laser BMD network.

"Strategically, there would be little to gain from such a space-based BMD system."

Let me note again that the actual deployment of a space-based ballistic missile defense is expressly prohibited under Article IV of the 1972 ABM Treaty. This prohibition extends to development, testing and deployment of such a system. The ABM Treaty is perhaps the single most important achievement in arms control to date. It has prevented a costly arms race in defense systems, and it has saved taxpayers a great deal of money. The United States and the Soviet Union have reaffirmed their commitment to this accord in Geneva. Nothing that I have seen to date would seem to warrant abandoning this cost-saving and strategically stabilizing agreement.

For over 2 years now I have urged that the United States and the Soviet Union return to the negotiating table to ban antisatellite weapons as a first step toward banning all weapons in space. If an arms race is to be avoided, we must begin to negotiate soon, since the Soviets presently possess and the United States will soon test and deploy an antisatellite weapon.

As I have frequently noted, the best time to stop an arms race is before it begins. As is evident from this most recent development on BMD, it will become increasingly difficult to reverse the momentum of a space arms competition once it gets under way. We should add to this the verification problems that will emerge that could make space arms control difficult, if not impossible.

"... the best time to stop an arms race is before it begins."

It should be noted that space systems are highly vulnerable to attack and, though we can develop countermeasures to protect our satellites, it can be stated with some degree of certainty that the Soviets will be working to defeat each package of countermeasures with a program of counter-countermeasures. There is nothing to be gained from a space arms race, but ever-increasing costs and ever-increasing instability.

We should not assume that by adopting laser technology we will steal a march on the Soviets. Moscow is said to be 5 or more years ahead of the United States in the development of directed-energy weapons. The Soviets currently spend three to five times as much on military space activities. It is in our interest to avoid an arms race in space with Moscow rather than seek to join them in such a competition.

I would urge Senators to consider Senate Resolution 43 which I have offered with eight cosponsors. This resolution calls on the President to immediately prepare a proposal and invite the Soviet Union to negotiate a verifiable ban on antisatellite weapons as a first step toward prohibiting all space-based and space-directed weaponry.

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PRO **HEFLIN**, cont. from page 78

tragic results, with our guard down.

Still, there are numerous critics who suggest that ballistic missile defense (BMD) is destabilizing. Their arguments should be challenged not only on first principles, but on the grounds that major reductions in offensive weapons are made more feasible if such weapons are protected by BMD.

It is not simply how many strategic weapons are allowed on each side, but how survivable those weapons are. Therefore, we must see to it that a strategic defensive policy that is basically conducive to arms control is not made to appear as the reverse.

I am convinced that it was our technical superiority in strategic areas which induced the Soviets to agree to the ABM treaty, as well as SALT I. When the ABM treaty was negotiated it was assumed major reductions in offensive ballistic missile forces would be shortly forthcoming. Instead, the Soviets stepped up their strategic programs on all fronts and, today, our land-based ICBM force stands vulnerable to a first strike. Vulnerability, I submit, is the most provocative and destabilizing condition of all, encouraging, at the minimum, international adventures backed by the threat of a first strike.

"It is not simply how many strategic weapons are allowed on each side, but how survivable those weapons are."

The ABM Treaty permits limited deployment by both sides, and the Soviets have a system deployed around Moscow. However, Congress decided in 1976 to phase out our deployed site at Grand Forks, S. Dak. Meanwhile, the Soviets have continued with a system-level program, at expenditures three times greater than ours, which we assume could be rapidly deployed in the future. The United States has pursued a modest R&D ballistic missile defense (BMD) program since the early 1970's, progressively developing means to defend our ground-based ICBM force and developing technologies which have provided remarkable advances for future defensive options.

I agree with President Reagan that we need to step up the pace of R&D on advanced long-range BMD concepts which will fully challenge our Nation's creative scientific capabilities for success and breakthroughs as well as our political willingness to seek visionary solutions. In this connection, I was one of the first Members of this body to speak out on the potential use of directed energy technologies, such as high-energy lasers, for future defensive weapons.

"In the future, we should be able to use ground-based or space-based, high energy lasers to destroy ballistic missile targets..."

In the future, we should be able to use ground-based or space-based, high energy lasers to destroy ballistic missile targets, as well as other offensive targets. I have felt for some time that we need to accelerate our efforts in the development of this technology. However, one of my primary concerns has been the fragmentation and lack of coordination among the various Government agencies of the current research and development in the area of directed energy.

This concern was amplified as a result of hearings that I chaired in late 1979. The purpose of these hearings was to provide a broader review of the highly diverse, important, and rapidly developing laser technology. From these hearings, I determined that we did not have the proper environment to focus this technology. Therefore, in the last Congress, I introduced legislation calling for a Laser/Particle Beam Institute to provide a long-range program in this area and serve as a coordinating and managing body for those Government agencies involved in laser/particle beam research and development.

While the President's March 23, 1983, announcement properly emphasized the

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Given the risks and costs of a space arms race, we must give arms control a serious try. Before we embark on this deadly competition, the American people must be convinced that we are engaged in this race because of Soviet insincerity, rather than for lack of serious negotiating efforts on our part. Americans have the right to demand this for they will pay the cost of space weapons and they will suffer the consequences that could follow from a deterioration of global security.

"Given the risks and costs of a space arms race, we must give arms control a serious try."

by Hon. Paul E. Tsongas

United States Senator, Massachusetts, Democrat

From a statement addressed to the Senate Committee on Foreign Relations in the course of hearings on May 18, 1983, to consider pending resolutions calling for a ban on space weaponry. Sen. Tsongas is a member of Senate committees on Energy & Natural Resources, Foreign Relations, and Select Small Business.

THE SUBJECT OF SPACE-BASED WEAPONS is one of the most crucial military and political issues facing the world today.

I would like to comment first about antiballistic missile systems. In my view the Administration's recent and highly publicized emphasis on ABM weapons is based on false strategic premises, and steers the arms control debate in a direction that can only benefit the Soviet Union. I would like to make three points to explain my thinking.

First of all, it is clear that there is no such thing as a perfect safety net to defend against Soviet nuclear weapons. There is no such thing now, nor do the most optimistic technological projections suggest that there ever will be. Only a few nuclear weapons can cause fearsome damage. No safety net can guarantee that at least a few nuclear weapons—carried by ballistic missiles, bombers or some other means—could not slip through our defenses. There is, unfortunately, only one way this country can deter such an attack: by maintaining the ability to inflict unacceptable damage on any potential aggressor.

"... there is no such thing as a perfect safety net to defend against Soviet nuclear weapons."

I wish it were otherwise, but that is the reality.

Second, ABM weapons are not defensive; they are offensive. They only serve to protect the aggressor nation from retaliation. The 1972 ABM Treaty was the result of the American ability to convince the Soviets of this reality. The reason is simple: an ABM system can be countered by launching more missiles than it can handle. But to do this with the missiles remaining after a massive, counter-force first strike would be extremely difficult. That is, it is possible to defeat an ABM system as part of a first strike; it may be impossible to do so in a retaliatory strike. Thus, ABM systems are part of a first strike capability, and provide less deterrence than the ability to retaliate in kind.

Third, all our ABM talk and our lack of action on arms control are fueling the Soviet propaganda machine.

Meanwhile, the popular movement for an end to the arms race grows here and in Europe. This propaganda war for the hearts and minds of the world is not going in our favor. While President Reagan hints at abrogating the ABM Treaty, Yuri

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more advanced, long-term BMD concepts, I would encourage him to seriously consider an evolutionary approach that also would include more mature, nearer term BMD concepts.

I have followed with great interest the progress in Army BMD systems and technology development centered at Huntsville, Ala. This program has made dramatic strides in recent years over a broad spectrum of systems.

"These technology successes provide vast encouragement to the hopes for a successful strategic defense in the future..."

As early as the 1960's, BMD demonstrated essential strategic defensive systems technologies, including phased array radars and Sprint-class interceptors. By the 1970's, the program technologies were developed to enable defense against sophisticated missiles in the terminal stages of attack through the use of complex data processing, and discriminating technologies, and quick-response interceptors. The program evolved in the 1970's with the development of on-board data processing and long-wave infrared sensors for early identification of targets outside the atmosphere. Today, BMD is demonstrating advanced sensors and data processing and smart missiles capable of intercepting incoming missiles with nonnuclear warheads. Programs also are already underway in the nontraditional technology areas of directed energy weapons.

These technology successes provide vast encouragement to the hopes for a successful strategic defense in the future and can be demonstrated, with the option for deployment, on an evolutionary basis while futuristic space-based systems concepts are maturing. Skeptics have dismissed the long-range portion of this thinking as a "Star Wars" fantasy, but I believe history will prove them to be wrong.

Secretary Caspar W. Weinberger recently noted:

"Perhaps one reason for the skepticism with which some have greeted this initiative is due to misunderstanding. Many would have you believe that we seek to develop a single system which can intercept and defend flawlessly against all missiles and all attacks. We know there is no such 'magic bullet'. What we are trying to develop first is a defense network—a series of systems, not necessarily based on the same technology or physical principles—which taken together will provide a reliable defense against nuclear ballistic missiles.

"Skeptics have dismissed the long-range portion of this thinking as a 'Star Wars' fantasy, but I believe history will prove them to be wrong."

"The concept we will need to perfect is not dissimilar to the one we now employ to defend our fleet against tactical missile attack. The layered fleet defense system consists of F-14 fighters and Phoenix Missiles at long ranges, the Aegis Cruiser at medium range, and close-in weapons systems. All are under control of computers which keep track of dozens of incoming missiles, and direct interceptors to destroy them. The ballistic missile defenses we seek to build must do these functions also, not against dozens of targets, but against thousands and at vastly greater ranges."

Secretary Weinberger was referring to a defense network, which I believe to be consistent with BMD's layered defense concept, where defense is possible in various regimes of an attacking missile's trajectory.

My interest in also considering more mature BMD concepts is based on several compelling factors that are consistent with the President's policy initiative. They can be fielded earlier and they can be securely based on our own soil. They would pose no threat for any use other than purely defensive objectives, and they would effectively complement any advanced systems that may be deployed later.

I am convinced that we should carefully and objectively evaluate the President's

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Andropov is offering to negotiate a complete ban on weapons in space. As public opinion shifts in Western Europe and elsewhere, the Soviets may conclude that they can obtain U.S. arms concessions without negotiating. We may end up with either no agreements or ones overly favorable to the Soviet Union. We only worsen our position by leaving the high ground to the Kremlin.

If we want to give the Soviets the greatest incentive to stick to the ABM Treaty, we must continue research work on potential ABM technologies. Our research will keep the Soviets honest because they would know that should they develop and deploy an ABM system in violation of the treaty we could match them tit for tat. But we should not make it a top national priority to develop an ABM system, particularly as this may involve violating an arms control accord. The 1972 ABM Treaty expressly forbids development, testing and deployment of ABM systems based in space. Thus, even to test an ABM system is to imperil the arms control efforts that ought to be our highest priority.

"If the United States tests its anti-satellite weapon, as is planned, we will enter a new and more dangerous phase in the arms race."

A second issue concerns anti-satellite weapons. The issue here is no less acute. We are approaching a watershed. If the United States tests its anti-satellite weapon, as is planned, we will enter a new and more dangerous phase in the arms race. The ASAT system we are about to test may not be amenable to verification. The U.S. ASAT consists of a small homing missile launched from a high-flying F-15. An F-15 carrying such a weapon would be undistinguishable from any other F-15. The missile itself kills by directly ascending up to the satellite and colliding with it, and the overall system should be markedly superior to current Soviet systems. To test this system could seriously reduce chances for obtaining a verifiable restriction on anti-satellite weapons. On the other hand, unilateral action on our part can lead to disaster. The Soviets have been testing their crude, co-orbital ASAT since the late 1960's. While the tests have only been partially successful, the Soviets do have an operational ASAT system, and we do not. We cannot expect the Soviets to negotiate a ban on weapons in space if we pursue a course of either stopping our own development of such weapons or pursuing this development willy-nilly, irrespective of the consequences for arms control.

"The ability to destroy Soviet satellites will not deter the Soviets from destroying our vital satellites during time of war."

The lack of such an agreement would seriously imperil our national security. While the Soviet Union can depend upon land lines of communication in a European conflict, we would have to depend upon satellite communications. Already, 70 percent of American military communications travel via satellite. Moreover, our military satellites provide us with communications and intelligence, and are also vital for verifying Soviet arms control treaty compliance. The ability to destroy Soviet satellites will not deter the Soviets from destroying our vital satellites during time of war. Thus, in all respects, obtaining an effective, verifiable ban on weapons in space and weapons to be used against spacecraft is in our national interest.

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call for the development of strategic defensive systems as a means of making nuclear weapons impotent and obsolete. If we raise ourselves above partisanship, as indeed we must, and look with open minds at what could represent a more stabilizing strategic policy, I believe we will come to agree that this initiative can signal a change in America's strategic policy that is likely to live in history as a dramatic turning point toward world peace. It puts us on a course that is fundamentally more secure and humane.

I believe America's scientists and engineers, who have brought this Nation to preeminence in world technology and to the Moon and back, can succeed in developing the defensive systems to make this peaceful vision a reality.

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by Hon. Fred C. Ikle

U.S. Under Secretary of Defense for Policy

From a statement accompanying Mr. Ikle's testimony on May 18, 1983, before the Senate Committee on Foreign Relations in the course of hearings on pending resolutions calling for a ban on space weaponry.

THE TECHNOLOGICAL REVOLUTIONS in the possible uses of outer space have opened new opportunities—as well as threats—for national defense. Both United States and Soviet Armed Forces use satellite systems. U.S. military space assets provide support for military operations, such as: communications, command and control, warning, navigation, and weather information. In fact, space systems are used increasingly for command, control and communications. Our launch detection satellites and strategic warning systems contribute to our nuclear deterrence. Space systems also enable us to monitor compliance with arms control agreements.

"...the U.S. military use of space is consistent with international law."

Needless to stress, the U.S. military use of space is consistent with international law.

Our military space programs are not simply a reaction to Soviet space activities but are the result of our continuing evaluation of the best means of achieving our national security objectives. We see space as a region in which supporting military operations may be carried out. While our programs are not a reaction to those of the U.S.S.R., we must, of course, take account of Soviet space activities. As in other areas, the Soviet approach to space differs considerably from our own.

"...the Soviet Union [has] clearly signaled its recognition of space as an arena in which to conduct war."

With the development and employment of an orbital antisatellite weapon over a decade ago, the Soviet Union clearly signaled its recognition of space as an arena in which to conduct war.

In the past 10 years, the U.S.S.R. has been launching more than 75 spacecraft per year, a rate of four-to-five times that of the United States. Over the past few years, the rate has been close to 100 annually. The annual payload weight placed into orbit by the Soviets is even more impressive—660,000 pounds—ten times that of the United States. This level of effort reflects the importance the Soviets attach to their space programs. But it may also reflect some technological weakness in the longevity and flexibility of their spacecraft. Soviet military and military-related space programs range from extended manned missions, to meteorological, communica-

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by Hon. Jim Leach

United States Representative, Iowa, Republican

From an address delivered on the floor of the U.S. House of Representatives on April 7, 1983. Rep. Leach is a member of House Committees on Foreign Affairs and Banking, Finance & Urban Affairs.

PRESIDENT REAGAN HAS CALLED upon the scientific community in our country to turn its great talents to the cause of mankind and world peace by developing space based antiballistic missile systems thereby, in the President's judgment, rendering nuclear weapons "impotent and obsolete."

Military strategists have for centuries stressed the need to occupy the "high ground." In the name of peace, the President asked the American people to lay down the technological gauntlet to the Soviet Union and launch what may prove to be the most exotic, expensive, and dangerous arms race yet, a race to dominate the ultimate "high ground"—outer space.

"If the United States and the Soviet Union do not pull back from the madness of the arms race, the era of space soldiers could be less than a decade away."

The concept of weapons in space has long been a staple of popular entertainment. But Buck Rogers is no longer science fiction. Yesterday's comic book fantasia is today's reality. If the United States and the Soviet Union do not pull back from the madness of the arms race, the era of space soldiers could be less than a decade away.

Security in the nuclear age implies being technologically second to none. But skeptics of the President's proposal point to towering obstacles involved in reliance on space-based deterrence:

First, orbiting battle stations, for instance, would be sitting ducks for counterforce weaponry;

Second, at relatively little cost, decoys and counters could be developed to confuse targeting systems and reduce the reliability of space-based weaponry;

Third, to provide effective deterrence, space based weapons would have to be 100 percent reliable; if only 1 percent of the Soviet Union's current missile force survived a launching, up to four nuclear warheads, each with a destructive power 30 times that of the bomb that destroyed Hiroshima, could be available for targeting on each of the 50 States;

Fourth, even if laser and particle beam technology proves generally effective against missiles, the possibility of developing other relatively invulnerable delivery systems remains; nuclear weapons, after all, can be carried by hand or transported in sail boats; 10 years ago, in fact, an American missile was stolen from a West German defense site and after dismantlement, transferred by mail to the Soviet Union; while the postal service is an unlikely strategic force—nuclear weapons not being as easily delivered as junk mail—the potential remains, without sizeable investment, to clandestinely place a weapon in another country and maintain detonation control from without; and

"...it is unlikely one side would allow the other to develop and put in place a weapons system without the other dedicating similar resources with similar effect."

Fifth, it is unlikely one side would allow the other to develop and put in place a weapons system without the other dedicating similar resources with similar effect.

Finally, and ironically, if one side appeared on the verge of establishing a foolproof defense system, incentives for the other to launch a preemptive strike would increase. Rather than enhancing global stability, the development of an invulnerable antimissile umbrella could precipitate the ultimate in brinkmanship. Strategic break-

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tions, navigational, reconnaissance, surveillance, targeting and antisatellite missions.

Since the U.S.S.R.'s successful launch of Sputnik I in 1957, the Soviets have pursued a vigorous and methodical program to exploit space for military purposes. The initial Soviet use of space for military applications occurred in 1961 with the launch of their first photographic reconnaissance satellite. Throughout the 1960's and 1970's, Soviet military space programs expanded in both scope and numbers. By now, these programs had developed into mature, integrated systems for the direct and indirect support of Soviet military forces, and with the capability to threaten low-altitude U.S. and allied satellites.

"On any given day, 70–110 Soviet satellites are in orbit, more than half of which serve primarily military purposes."

On any given day, 70-110 Soviet satellites are in orbit,more than half of which serve primarily military purposes. Some 85 percent of all Soviet space launches are primarily military or joint military/civilian missions.

It appears that the Soviets are developing a re-usable space system, similar to the U.S. space shuttle, and a smaller space plane. Orbital developmental test flights of the smaller vehicle have already occurred. These systems could be in regular use within a decade and will further expand the military flexibility and capability of the Soviet space effort.

Soviet manned space missions are becoming increasingly complex and constitute the single most extensive element of the Soviet space program. After accomplishing many firsts in the early 1960's, including the first man in space, the Soviet manned program was momentarily overshadowed by the U.S. manned program during the late 1960's. Since 1971, the Soviets have placed seven space stations in orbit. The first Salyut I manned space station was launched in 1971. A second type of Salyut station was launched in 1973. Both were capable of conducting military research.

By 1977, the Soviets had developed the capability to resupply and exchange personnel on their Salyut space stations. On three occasions the Soviets have conducted manned missions lasting as long as 6 months. With completion in 1982 of the 211 day mission, the Soviets set a new record.

"The Soviet commitment to their manned space program is growing."

The Soviet commitment to their manned space program is growing. The development of a large manned space station by about 1990 to maintain a military presence in space is, we believe, one of the goals of the new heavy-lift launcher systems now in development. The Soviets also will use the heavy-lift space boosters to orbit even larger space stations and space modules before the end of the century. Such space stations could weigh more than 100 tons and be able to support a large crew for extended periods without replenishment.

The U.S.S.R.'s introduction, application and known future development of space weapon systems point to a coordinated program involving:

The present generation of antisatellite vehicles, now operational and designed to destroy low-orbiting satellites.

A very large, directed energy research program including the development of laser-beam weapons systems which could be based either on the ground, or aboard the next generation of Soviet antisatellite systems or Soviet manned space stations.

The operational Soviet antisatellite system has the capability to destroy U.S. space systems in near-Earth orbit. The Soviets conduct yearly tests to practice satellite interception and to refine the ASAT system. We believe that one of the purposes of the Soviet Union's space weapons program is the development and deployment of a space-based laser. The Soviets could launch the first prototype of a

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throughs in an era where weapons themselves are of civilization-destroying proportions destabilize the nuclear balance and thus generate Strangelovean calculations that defy normality and, potentially, morality.

Until Hiroshima, the history of warfare could be characterized as a vacillation between the preeminence of the forces of offense and those of defense.

A maginot line mentality which refuses to recognize that there is no shield mightier than the nuclear sword undercuts any rationalization for arms control. It leads not only to questioning of the desirability of seeking future arms agreements, but to a reappraisal of past ones.

To date, arms control advocates have criticized the President for not pursuing new arms agreements as forthrightly as they would prefer. The President's avowed intention to launch a new arms race in space raises a more alarming specter: the possibility that an American President would renege on the only agreement legally in force between the superpowers.

"The President contends that only if the United States demonstrates a commitment to develop new weapons will the Soviet Union come to the bargaining table..."

The 1972 ABM treaty declares: "Each party undertakes not to develop, test, or deploy ABM systems or components which are sea based, space based, or mobile land based." The administration holds that merely conducting research of the type hinted in the President's speech does not violate SALT I, but clearly fulfillment of the President's loosely described "vision of the future"renders meaningless the terms of the agreement.

The President contends that only if the United States demonstrates a commitment to develop new weapons will the Soviet Union come to the bargaining table, and only by realistically appraising Soviet intent can we fashion appropriate foreign policy initiatives and responses. The President's two principal speeches, however, may prove counterproductive. In his "Star Wars" speech, the President challenged the sanctity of past agreements and implicitly the word of the U.S. Government. In his "Darth Vader" pronouncements to Evangelical Christians in Orlando, he implied agreements might never be possible with the Soviet Union.

Describing the Soviet empire as "the focus of evil in the modern world," President Reagan imbued cold war rhetoric with holy war symbolism. If the Soviet Union is evil incarnate, any President who signs an arms control agreement presumably would put himself in the position of selling his country's soul to the Devil. It would perhaps be too harsh a judgment to conclude, as America's preeminent historian Henry Steele Commager recently did, that the Orlando speech was the worst speech ever delivered by an American President. But the implications for arms control must be considered worrisome.

"Time is running out on our ability to control space-age weapons."

Russians are a proud people. The Soviet system is repressive, but little good would seem to be served by political posturing. Now is the time to deescalate rhetoric and stop the nonsense of name calling. Global survival requires that at a minimum we posit sanity on the Soviet side and recognize that mutual self-interest demands a forthcoming approach to arms control.

Einstein once remarked that unleashing the power of the atom has changed everything except our way of thinking. Time is running out on our ability to control space-age weapons. If "Star Wars" is to remain fiction, statesmanship must catch up to the realities of modern science.

One of the foremost principles of arms control is that it is far easier and more manageable to make agreements prohibiting what has not taken place than to

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small space-based laser antisatellite weapon in the late 1980's or early 1990's. A system capable of attacking other satellites within a few thousand kilometers range might be possible in the 1990's. Space-based ABM systems could be tested in the 1990's, but probably would not be operational until after the turn of the century.

The Soviets have steadily increased their space photographic and electronic reconnaissance effort since the early 1960's. Each year over 50 of these satellites are launched to support military forces on a daily basis. The Soviet military space program also reflects an ever-increasing use of space for world-wide surveillance and warning. The Soviets have brought a number of United States and allied military forces under surveillance by these space-based systems. The surveillance satellites include an ICBM launch detection system and ocean surveillance systems, such as the two nuclear-powered satellites that caused worldwide alerts during their breakup and reentry into the Earth's atmosphere in 1978 and early 1983. Soviet efforts in the surveillance field are expected to lead to a multi-satellite detection, surveillance and attack-warning system against strategic and non-strategic ballistic missiles and possibly bombers as well.

"The Soviet military space program... reflects an ever-increasing use of space for world-wide surveillance and warning."

The Soviets also are increasing their use of space systems for command, control, and communications. Since the mid-1960's when their first communications satellite was launched, the U.S.S.R. has continued to improve and expand its communications satellite programs to support its political leadership and its military, diplomatic and intelligence mission.

The Soviets have embarked on an ambitious expansion of their communication satellite program that will significantly enhance their global command, control and communications capability. Over the next 10 years, the Soviets will develop and deploy an even more advanced series of communication satellites, some of which might relay transmissions from manned orbital command and control platforms.

Let me now turn to our own activities. In support of our national security, the Department of Defense acquires and operates space systems and pursues space-related research and technology development projects.

"..Soviet development of an operational antisatellite capability presents the potential for space to become a hostile environment."

As noted, Soviet development of an operational antisatellite capability presents the potential for space to become a hostile environment. Therefore, the DOD space policy directs that military space systems, including essential ground elements as well as orbiting spacecraft, be designed, developed and operated to enhance their survivability and endurance.

Since 1977, it has been U.S. policy to pursue the continued development of an operational, non-nuclear antisatellite capability. If we have a credible retaliatory capability, we are better able to deter attacks against our space systems.

We are currently signatories of at least three treaties which affect certain military activities in space: the Outer Space Treaty, the Limited Test Ban Treaty, and the Antiballistic Missile Treaty.

The Outer Space Treaty prohibits, on the Moon and other celestial bodies, the establishment of military bases, installations, and fortifications, the testing of any types of weapons, and the conduct of military maneuvers. This treaty also prohibits the placement in orbit around the Earth, installation on the Moon or other celestial bodies, or stationing in outer space of any objects carrying nuclear weapons or any other "weapons of mass destruction." The testing or orbiting (in outer space proper) of weapons using conventional explosives is not prohibited.

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CON **LEACH,** cont. from page 87

attempt to restrict weapons or troops deployments which have become a standardized part of a particular country's arsenal or which are current de facto military situations. SALT I restrictions on ABM systems were successfully developed precisely because they were agreed upon before, rather than after, significant deployment. The logic that led to the SALT I agreement prevails today. Security is better enhanced by arms control than by arms races. Space should be explored, not exploited.

It has been noted by many that President Reagan has more potential to reach arms control agreements than a President perceived to be more liberal, because he commands the respect of those who might be expected to object to serious arms control. Like Nixon going to China, Ronald Reagan can go the the Moon on arms control. The President's critics must understand that administration initiatives—the proposal of a one-third reduction in nuclear warheads; the zero-option INF position; the recent draft convention on chemical weapons; and, most importantly, the willingness to stay at the bargaining table—represent a first step. The President's supporters, however, must understand that the successful conclusion of any agreement will take greater flexibility and professionalism than has so far been evidenced. Perspective is demanded on all sides, but global patience is wearing thin.

"Security is better enhanced by arms control than by arms races. Space should be explored, not exploited."

Swords can no longer be blunted by shields. They must, as Scripture implores, be beaten into plowshares.

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by Daniel Deudney

Senior Researcher, Worldwatch Institute

From testimony presented on April 14, 1983, before the Senate Committee on Foreign Relations in the course of hearings on pending resolutions calling for a ban on space weaponry.

BUFFETED by the MAD (mutually assured destruction) men telling him to perpetually assure our destruction and the NUTS (nuclear utilization theorists) telling him to prepare to fight nuclear wars, President Reagan looked to the heavens in hope of finding salvation from our deepening peril.

He looked in the right direction. Space technology can be the cornerstone of an alternative security system, the foundation of an international order that does not rely upon evermore massive arsenals of nuclear weapons.

If we can avoid using space as another arena for conflict and instead use it as a medium for mutual benefit, we will have taken a giant step toward enduring peace.

"If we can avoid using space as another arena for conflict... we will have taken a giant step toward enduring peace."

Space technology is at the core of the present superpower standoff. The first military space technology, ballistic missiles, used space as a corridor for high speed unobstructable attack, thus enabling the Soviets to outflank American dominance of air power and directly threaten the United States. The second use of space technology for military purposes, reconnaissance satellites, enabled the United States to roll back the veil of Soviet secrecy and monitor in detail the Soviet military machine.

The ominous movement over the last decade toward fighting a nuclear war is in large part the consequence of the satellite "force multipliers": geodetic satellites to

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The 1972 ABM Treaty prohibits the development, testing, and deployment of space-based ABM systems and components (article V). Should future technology bring forth new ABM systems "based on other physical principles" such as lasers and particle beams, as opposed to those employed in current systems, it was agreed that limiting such systems would be discussed before deployment in accordance with the treaty's provisions for amendment.

In conclusion, let me say a few words about the President's initiative on strategic defense. The President decided that we embark on a program to counter the Soviet missile threat with measures that are defensive. He directed a comprehensive and intensive effort to define a long-term research and development program toward the goal of eliminating the threat posed by nuclear missiles. This development could be—indeed should be—complemented by arms control measures.

"The President decided that we embark on a program to counter the Soviet missile threat with measures that are defensive."

In accordance with the President's decision, the Defense Department, in cooperation with other agencies, has initiated a two-pronged effort: one to explore and prioritize the technologies, and the other to develop and define the policy and strategy options. We are not envisioning a single system to intercept and defend against all missile attacks. Our research is designed to explore a defense network—a series of systems not necessarily based on the same technology or physical principles—which taken together will provide an effective defense against nuclear ballistic missiles for us and our allies. We recognize full well that this is a long-term effort whose fruits may not be available until the next century.

Because this is a long-term effort we need to be clear, as the President explained, that we must continue for the interim to rely on deterrence to preserve the peace. We also must—and will—continue to pursue agreed reductions in nuclear arms that are balanced, and verifiable. Because our search for defensive technologies has the goal to reduce the threat of ballistic missiles, it is fully consistent with the arms reduction effort we are pursuing today in the START negotiations. It supports those efforts by offering the prospect that the effectiveness and role of ballistic missiles may be reduced sharply in the future. The President's initiative is, of course, also fully consistent with existing arms control agreements. While the ABM Treaty prohibits the development, testing or deployment of ABM systems, it does permit research.

"The essence of the President's decision on strategic defense... is that it opens up alternative avenues to preserve the peace in the nuclear age."

The essence of the President's decision on strategic defense, in my view, is that it opens up alternative avenues to preserve the peace in the nuclear age. President Reagan's successors—in the next decade, or in the first decade of the next century—need not have their options limited by the strategic notions that were fashionable in the 1970's. Our strategic planning has been restricted far too much by the idea that defensive systems are bad and that we can and must, indefinitely, remain locked into a confrontation of all-powerful, offensive missile forces. We owe it to the next generation to make a determined search for better alternatives.

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CON **DEUDNEY,** cont. from page 89

improve the accuracy of missiles; communication satellites to coordinate strikes or retaliation; and navigation satellites (such as the NAVSTAR GPS) to make submarine launched missiles as accurate as land-based ones. The present effort to upgrade U.S. surveillance satellites by giving them "real time" data links through relay satellites will turn an arms control monitoring system into a war-fighter for targeting mobile forces and performing postattack damage assessment.

Regulating these war-fighting information services without constraining important civilian and arms control verification treaties would be difficult, if not impossible. This makes it all the more imperative that agreements limiting long-range ballistic missiles be signed in the near future.

"..the next move in this deadly game of leap-frog may well be a Soviet laser orbital battle station intended to cripple satellites."

We are now at a major turning point in the military use of outer space—the beginning of a race to put weapons into space.

The first antisatellite weapon, ASAT, an American system, employing nuclear warheads, was tested and deployed. It was dismantled because it was too indiscriminate in its destructiveness and, with the Limited Test Ban, could no longer be tested.

The second ASAT, a Soviet orbital rendevous system using conventional explosives, has been tested some two dozen times with about a 50 percent rate of success. This system, which cannot reach most U.S. military satellites, is launched from a large, distinctly configured Soviet rocket requiring extensive support facilities, and providing plenty of warning time.

The United States is about to begin testing an air-launched direct ascent system that will destroy through high speed collision. The U.S. system will be capable of striking a high percentage of Soviet military satellites, is small and hard to distinguish from other air launched missiles, and will give little warning time.

If history is any guide, the next move in this deadly game of leap-frog may well be a Soviet laser orbital battle station intended to cripple satellites. Given the Soviet tendency to deploy much earlier in the development cycle than the United States, and the immense technical problems associated with such a system, it will probably have negligible capability—except to reduce warning time. But as with Sputnik the psychological impact will probably be traumatic, leading the United States to embark upon an ambitious crash program to put battle stations into orbit. The result will be a full scale arms race in space.

"With weapons in space every satellite malfunction could be the harbinger of a surprise attack."

What are these weapons for and what strategic purpose will they accomplish? How will our security be affected?

The antisatellite capabilities will be important components of a first strike against early warning satellites. Far less plausible is their use in a protracted nuclear war—their official justification.

ASATs will, however, increase the chances for accidental nuclear war. The eyes and central nervous system of our already far flung nuclear strike forces are in space. With weapons in space every satellite malfunction could be the harbinger of a surprise attack. The Archduke Francis Ferdinand of World War III may well be a critical U.S. or Soviet reconnaissance satellite hit by a piece of space junk in a crisis situation.

Predicting how the more speculative larger scale systems would be used hinges on many unknowables. But it seems improbable that they would be capable of stopping a full-scale pre-planned first strike. Far more plausible is their use as part of a first strike to "mop up" those missiles that escape destruction on the ground.

(Continued on page 93)

PRO Continued from page 90

by Lieutenant General Daniel O. Graham

United States Army, Retired

From testimony presented on April 14, 1983, before the Senate Committee on Foreign Relations in the course of hearings on pending resolutions calling for a ban on space-based and space-directed weapons. Gen. Graham is Director of High Frontier, an organization concerned with the U.S. defense posture relative to space weapons systems.

I BELIEVE IT WOULD BE A TRAGEDY INDEED for the United States to follow the Soviet lead in banning all weapons in space. Two weeks after the first flight of the U.S. space shuttle Columbia, Premier Breshnev of the Soviet Union came forward with a public announcement that a treaty should be signed banning all military weapons in space.

"...it would be a tragedy indeed for the United States to follow the Soviet lead in banning all weapons in space."

From the Soviet point of view, this was a smart move, and indeed it was followed up later by the Soviet proposal for a U.N. treaty to that effect. It was good strategy for the Soviets because they recognize the fact that the United States had reached a position in space technology where the Soviet advantage in nuclear first strike capability residing in their superior force of long-range ballistic missiles could be nullified. The Soviets knew that the shuttle represented a transportation system to space over which the United States could move the men and material necessary to protect the free world from Soviet nuclear first strike or nuclear blackmail.

To follow the Soviet lead by banning all weapons in space, as opposed to banning nuclear weapons in space which has previously been agreed to, would be to deny to the United States our only chance to deliver ourselves and our posterity from the brooding menace of the balance of terror doctrines of mutual assured destruction. By putting into space a nonnuclear defensive system, we can deny to the Soviet Union any hope of an effective first strike with their huge intercontinental ballistic missiles.

A system such as that proposed by High Frontier would have no capability whatever of killing a single Russian, but could deny to the Soviet Union its first strike capability, not an effective retaliatory capability. Such a system could be deployed quickly and at reasonable cost if we use the technology currently available to us, already paid for by the taxpayers.

"By putting into space a non-nuclear defensive system, we can deny to the Soviet Union any hope of an effective first strike..."

Once in place, we can discard the awesome doctrine of mutual assured destruction and base our deterrence on a new strategy of assured survival. As President Reagan has said, we will then be able to save lives, rather than merely threaten to avenge them.

The historic opportunity will surely be lost if the Senate of the United States persuades the Government to adopt the policy of banning even such patently defensive nonnuclear systems in space. Indeed, such a policy will perpetuate the mutual assured destruction doctrine and force us for the foreseeable future to live as hostages in the balance of terror strategic situation in which we find ourselves today.

For those who are most interested in arms control, I should point out that our arms control negotiations to date have been based on the attempt to maintain a balance within the balance of terror. If indeed we go to space-borne defense, it is perfectly logical to approach the Soviet Union this way, to say Ivan, you have said

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CON **DEUDNEY,** cont. from page 91

Large-scale space weapons would be an example of what I call a destruction entrusted automatic device (DEAD). Space weapons could never be commanded and controlled by humans. A space laser, for example, would have about five minutes to detect, target and engage an ICBM in the boost phase. One Department of Defense analyst put it this way. "We would have to delegate the decision-making to the weapon system itself and we have had no experience in that type of operational system." To start a nuclear war in the MAD era would have required a major political misjudgment; with space weapons a machine malfunction would be sufficient.

Large-scale space weapons would be but one example of our potentially fatal drift to adopt DEAD strategies. Perhaps the most widely discussed strategem involving DEAD is "launch on warning." As attacks against even the most hardened missile silos grow in probable success, there is a strong temptation to prepare to launch the vulnerable missiles before the barrage of attacking warheads arrive. With somewhere between 15 and 30 minutes warning and response time for intercontinental ballistic missiles the civilian leadership is, as they say in Pentagonese, "out of the decision loop." In simple terms, the military would have the authority as well as the ability to fire a salvo of nuclear missiles in response to radar and computer images of attack. Thus far neither the United States nor the Soviet Union has adopted—at least publicly—a launch on warning strategy, although U.S. military planners speak of such a posture to make the MX "survivable." And the Soviet leaders have said they will be forced to place its forces on such hair-trigger alert, if the NATO deploys the Pershing II missile, capable of striking hardened targets deep within the Soviet Union in 5-8 minutes. "Speed" observes U.S. Defense official Fred Ikle, "is the tightening noose around our neck."

"Space weapons could never be commanded and controlled by humans."

The construction of an anti-ballistic missile (ABM) system capable of shooting down on-coming nuclear missiles would also require the delegation of control to machines. During the late 1960s when the United States, after acrimonious international debate, decided to build a limited anti-ballistic missile system, a major objection leveled by critics of the plan was that the nuclear anti-missiles would have to be fired without Presidential authorization and, in the case of close-range "terminal defense," without human intervention. Fortunately, the superpowers agreed in the ABM Treaty of 1972 not to deploy missile defenses, sparing the world another step toward self-destruction.

"...space weapons promise to bring humanity to the edge of cybernetically-initiated annihilation."

The accidental triggering of a "defensive" system seems at first glance to be far less ominous than the accidental launch of a nuclear missile. Yet with space weapons this distinction largely disappears. Since both sides would have hundreds of very large automatically controlled battlestations in orbit, the likely target of a malfunctioning satellite would be another such satellite (perhaps even one of its colleagues). Since any first strike would require as a first step the attack on the other side's "defensive" satellite system, the inadvertant destruction of such satellites would be indistinguishable from a first strike. Thus a space-based ABM or ballistic missile "defense" system would be far worse than a terrestrial-based one because a malfunctioning earth-based unit would not destroy a potential antagonist's critical military systems. Instead of offering an escape from the tightening nuclear noose, space weapons promise to bring humanity to the edge of cybernetically-initiated annihilation.

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PRO GRAHAM, cont. from page 92

that you do not wish to first strike the United States. You will excuse us if we worry about that since many of your weapons systems seem to be designed to do just that.

We are therefore going to put into space a defensive system which will deny any country the capability of first-striking the United States with nuclear ballistic missiles. Since you have no intention of doing that, you won't mind, of course, will you?

"...High Frontier uses kinetic energy kill; that is, a kill of the Soviet weapons with pellets, like buckshot."

Further, you may not believe the United States when we say we have no intention of first-striking the Soviet Union. But if you Soviets don't believe us, then we invite you to put a similar system in space yourself.

I should point out that the High Frontier system that I have spoken of does not employ lasers and does not employ particle beam weapons or any futuristic Buck Rogers system. In fact, High Frontier uses kinetic energy kill; that is, a kill of the Soviet weapons with pellets, like buckshot.

If you worry that this is not technically feasible, I would like to call your attention and the attention of your staffs to a document recently declassified by the Department of Defense which was Project Defender. In Project Defender, in 1962, 20 of the best scientists within the Department of Defense, backed by a staff of 5,000 technicians and administrative personnel, came to the conclusion that a defense such as High Frontier's could have been deployed by 1968.

So we are not talking Buck Rogers when we back the President's call for a defense in space. We do not have to have lasers or particle beam weapons, although High Frontier has no objections to such weapons and a second generation may include them. The fact of the matter is that within 5 or 6 years, at a cost not of many billions but of $15 billion, a strategic defense can be had by this country. If President Reagan runs again, he may see a space-borne defense against the long-range Soviet ballistic missiles during the period of his Presidency.

"...within 5 or 6 years, at a cost of...$15 billion, a strategic defense can be had by this country."

Now we have had contests that what we say will cost much more. As a matter of fact, we had correspondence from the Deputy Secretary of Defense, who said that we were wrong, that in fact it would cost $50 billion.

Well, we don't agree with the Department of Defense. We think it will cost far less. But even if it did cost $50 billion, this is less than it would have cost us to deploy the racetrack deployment scheme for MX. And all that would have done is to add 200 more missiles to our inventory.

We offer to this country once again what the country should be able to expect from its government, which is protection against the worst threat that the United States of America has ever faced, and that is the threat of destruction within 35 minutes of a Soviet decision to fire its long-range ballistic missiles.

That this is technically feasible was proved 20 years ago. All that is required today is the political will to do so. But also required is a realization that this new arena of human activity called space must be used to its utmost by the United States for the defense of this country and of its allies and for the promotion of industry in space and this should be done as quickly as technology will allow.

CON **DEUDNEY,** cont. from page 93

Space war will also largely preclude the peaceful use of outer space. We rightly think of space as infinitely vast, but in doing so we forget that the earth's orbital space is limited and subject to the same problems of crowding and resource degradation we face on earth. Already space junk—small bits of debris flying about in various odd orbits— is a growing problem. Further ASAT tests involving explosions and collisions will add greatly to this problem. Testing the X-ray laser system would damage important civilian satellites with electromagnetic pulse (EMP). By the late 1980s over 100 communication satellites in geosynchronous orbit, worth between five and ten billion dollars, will be in jeopardy. In a very real sense we face an either/or choice: science, information services, and earth monitoring from space—or weapons in space.

"Space war will also largely preclude the peaceful use of outer space."

The present arms control regime for space weapons—the *Limited Test Ban Treaty,* the *ABM Treaty* and the *Outer Space Treaty* has worked remarkably well, but contains important loopholes through which space weapons can pass. To abandon these treaties because of their loopholes would be like dynamiting a leaky dike at high flood rather than plugging the leaks.

Fortunately, we are at a stage where weapons in space can be stopped before they are ever extensively tested and deployed. Space weapon development is no further along than air war was when World War I biplane reconnaissance pilots carried hand guns. Most importantly, because so little has been tested, truly comprehensive controls are relatively easy to construct and verify.

The control of weapons in space simply clears the stage for the use of space technology to improve both arms control verification, and our relations with the Soviets. This positive space security agenda emphasizes the unique role of space technology in providing *mutual assured security* and mutual benefits.

First, *expand the use of space for crisis monitoring.* The recently proposed establishment of an orbital joint U.S.-Soviet command center should be a priority.

Second, *establish an International Satellite Monitoring Agency (ISMA).* An ISMA would permit the Security Council to monitor crises and border disputes and would lay the groundwork for monitoring compliance with the treaties banning chemical and biological warfare and environmental modification.

"Either we move now to comprehensively ban weapons from space or we will have a major new arms race on our hands."

Third, *conduct joint missions with the Soviets.* A U.S. Administration, looking for a bold, high visibility, quick pay-off way to cut through gathering clouds of suspicion and war, would find a joint U.S.-Soviet manned space mission particularly appealing.

Unlike in 1976 when the Apollo-Soyuz rendezvous was a meeting of two parallel systems, the space shuttle and the Salyut stations are perfect complements for each other. What better way to find out what's going on in Soviet space stations or to allay Soviets' suspicions about the shuttle than to take each other for a ride? More routine cooperation in space and the consequent commingling of space scientists would make much harder concealed weapons work.

The world is at a critical juncture. Either we move now to comprehensively ban weapons from space or we will have a major new arms race on our hands. Space technology can be the foundation of an alternative security system—if we ban weapons now.

Treaties Involved

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not reconstructed, are said to require an on-site inspection agreement. According to analysts, the Soviet SS-9 will probably continue in production for use as a satellite launcher. Small ASAT payloads could be hidden from on-site investigators or moved off-base until after they had left.

U.S. defense planners are concerned that only a relatively few American satellites would have to be "neutralized" to have a serious effect on our strategic posture. Even if only a few Soviet ASATs escape the verification process, the result would be a severe impact on national security.

Action in the Current Congress

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verifiable ban on ASATs; and (2) that pending such an agreement, such tests are necessary for the national security."

Separately, on July 21, Senator Wallop introduced an amendment to increase funding for space-based laser programs by $125 million. He also sought to transfer the program from the Defense Advanced Research Projects Agency to the Army's Ballistic Missile Defense Office. The amendment was defeated 65-27.

DOD Appropriations Bills

During mark-up of the DOD Appropriations Bill, H.R. 4185, the House Appropriations Committee deleted $19.4 million for procurement of the U.S. ASAT pending a report on the President's policies regarding arms control in space.

The Senate disagreed. During conference a compromise was reached. Money will be withheld until a report is submitted, after which it may be spent. The report must be submitted by March 31, 1984. The bill passed both Houses and was signed into law on December 8, 1983.

FY84 Funding

For Fiscal Year 1984, DOD requested $9.9 billion for space-related activities. Congress appropriated that amount, although funding within some categories was redirected.

The DOD Authorization Bill was signed into law on September 24, 1983 (Public Law 98-94). The Military Construction Authorization Bill was signed into law on October 11, 1983 (Public Law 98-115) and the Military Construction Appropriations Bill became law on the same day (public Law 98-116).

Congress denied $2.75 million requested by the Air Force for advanced military manned space systems, such as "space cruisers." Congress also approved $559 million requested for the Space Shuttle in the DOD Authorization and Appropriations measures—$337.4 million for research and development; $195.3 million for procurement; and $26.84 million for activation of the Vandenberg shuttle launch site.

In the Military Construction Bill, however, there was disagreement over funding for items relating to Space Shuttle facilities. In considering the Military Construction Appropriations Bill, the House deleted $6.6 million for construction of a shuttle external-tank area icing protection facility at Vandenberg, and $700 million for security modifications at NASA's Johnson Space Center. The Senate approved the funding and the conference report approved the icing protection facility, but adopted the House position on denying funding for security modifications at the Johnson Space Center; and denying $6 million of the $14 million requested for Vandenberg security modifications.

Other Space Programs

Congress approved virtually all requested funding for space-related items in the DOD budget, including $335 million for NAVSTAR; $220 million for AFSATCIM; $158 million for the Defense Satellite Communications System (adding language to permit multi-year procurement for this system); $61 million for meteorological satellites; $123 million for FLTSATCOM; and $150 million for MILSTAR. Funding for the Integrated Tactical Surveillance System, including space-based radars to track ships, was reduced from $30.2 million to $12 million, mainly because of congressional concern that projects within the ITSS category had been separated out and require review.

FY85 Funding

Funding levels for FY85 have not been determined. Two approaches to funding the ballistic missle defense development program have been suggested. The first is "fiscally constrained," with recommended levels of $1.3 billion in FY84; $1.9 billion in FY85; $2.5 billion in FY86; $3.1 billion in FY87; $3.7 billion in FY88; and $4.3 billion in FY89. The second is "technology limited," with recommended levels of $1.3 billion in FY84; $2.3 billion in FY85; $3.4 billion in FY86; $4.3 billion in FY87; $4.6 billion in FY88; and $4.9 billion in FY89.

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26 Church Street • Cambridge, Massachusetts 02238 • (617) 547-5552

ANTI-SATELLITE WEAPONS:
ARMS CONTROL OR ARMS RACE?

June 30, 1983

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FOREWORD

This document was prepared by a panel organized under the auspices of the Union of Concerned Scientists. The participants were:*

Kurt Gottfried, **Panel Chairman**, Member, Board of Directors, Union of Concerned Scientists; Professor of Physics and Nuclear Studies, Cornell University.

Hans A. Bethe, Professor of Physics Emeritus, Cornell University; Nobel Laureate in Physics; Chief, Theoretical Division, Manhattan Project; Member, President's Scientific Advisory Committee (1957-60); Strategic Military Panel (1957-69).

Richard L. Garwin, IBM Fellow at the Thomas J. Watson Research Center; Member, President's Science Advisory Committee (1962-65) and (1969-72); member, Defense Science Board (1966-69).

Noel Gayler (Admiral, USN, Ret.), former Director, National Security Agency; former Commander-in-Chief, U.S. Forces in the Pacific; former Deputy Chief of Naval Operations (Research and Development).

Henry W. Kendall, Chairman, Board of Directors, Union of Concerned Scientists; Professor of Physics, Massachusetts Institute of Technology.

Franklin A. Long, Professor Chemistry Emeritus, Cornell University; former Associate Director, U.S. Arms Control and Disarmament Agency.

Leonard C. Meeker, member, Board of Directors, Union of Concerned Scientists; U.S. Ambassador to Romania (1969-73); Legal Advisor to the Department of State (1965-69).

Carl Sagan, Professor of Astronomy and Space Sciences and Director, Laboratory for Planetary Studies, Cornell University.

Herbert Scoville, Jr., Deputy Director, Research, Central Intelligence Agency (1955-1963); President, Arms Control Association.

John Steinbruner, Director of Foreign Policy Studies, Brookings Institution, 1978-present; Associate Professor of Organization and Management, Yale University, 1976-1978.

* The affiliations listed are for purposes of identification only.

ACRONYMS FROM TABLES 1 AND 2

AFSATCOM	— Air Force Satellite Communications System
DMSP	— Defense Meteorological Satellite Program
DSCS	— Defense Satellite Communications System
DSP	— Defense Support Program
ELINT	— Electronics Intelligence
EORSAT	— ELINT Ocean Reconnaissance Satellite
FLTSATCOM	— Fleet Satellite Communications System
GLONASS	— Global Navigation Satellite System
GEOS	— Geodynamic Experimental Ocean Satellite
IONDS	— Integrated Operational Nuclear Detection System
LAGEOS	— Laser Geodynamic Satellite
LES	— Lincoln Experimental Satellite
MARISAT	— Maritime Satellite
NAVSTAR	— Navigation System using Time and Ranging
NOAA	— National Oceanic and Atmospheric Administration
NOSS	— Naval Ocean Surveillance Satellite
NTS	— Navigation Technology Satellite
RORSAT	— Radar Ocean Reconnaissance Satellite
SDS	— Satellite Data System

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Richard L. Garwin, Noel Gayler and Kurt Gottfried presented a summary of this report at a hearing, called for this purpose, before the Senate Foreign Relations Committee on May 18, 1983. The position of the Reagan Administration was presented by Kenneth Adelman, Director of the Arms Control and Disarmament Agency, and by Fred C. Iklé, Under Secretary of Defense for Policy. The printed record of the hearing includes a somewhat briefer version of this document. Responses to the written questions posed by Senators Claiborne Pell and Larry Pressler are reprinted here as Appendix II.

The panel has benefitted from suggestions or criticisms by Robert W. Buchheim, Abraham Chayes, Daniel Deudney, William J. Durch, Donald L. Hafner, Spurgeon Keeny, Walter Slocombe, and Herbert F. York. The panel would also like to express its gratitude to Peter Didisheim, Kathleen Gilroy, Charles Monfort, John Pike, Howard C. Ris, Jr., Joshua Sarnoff, Irene Silverman, Nancy Stockford, and John Tirman.

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1. SUMMARY

Satellites give the United States prompt, precise, and irreplaceable intelligence about Soviet strategic forces. They provide an invaluable view of many other aspects of Soviet military capabilities and activities. In a crisis, they would allow each side to watch the movements of the other, to gauge its objectives and apprehensions. If hostilities were ever to break out between the superpowers, whatever hope there would be for controlling nuclear conflict and bringing it to an early end would largely rest on satellite surveillance, on the command of strategic forces via satellites, and on satellite communication between the adversaries.

But satellites are two-edged swords. They have a beneficial role in arms control, confidence building, and conflict resolution, but their unique ability to see, to hear, and to communicate greatly amplifies the effectiveness of the military forces that they serve. As a result, they become exceptionally tempting targets as soon as hostilities are about to begin.

In the 1960s, both the U.S. and the Soviet Union fielded systems having anti-satellite (ASAT) capabilities. The United States eventually dismantled its ASAT systems and adopted the position that its national security would be best served by abstaining from competition in ASAT weaponry. The Soviet Union, on the other hand, continued sporadic testing of a rather primitive device that can attack objects in low earth orbits.

By the latter part of the 1970s, the United States altered its approach, though a weapon-free space environment continued to be its goal.[1] The new tactics had both a military and a diplomatic component: a program to develop a satellite interceptor, and simultaneous negotiations towards a treaty that would ban the testing and deployment of ASAT weapons. These negotiations did not reach fruition during the Carter Administration,[2] and have not been pursued since then.[3] In the interim, both superpowers' ASAT programs have continued apace.[4]

In August 1981 the Soviet Union submitted to the United Nations a draft treaty calling for a "prohibition on the stationing of weapons of any kind in outer space." The United States has not responded to this initiative, nor has it offered any rationale for its failure to respond. If the United States continues to forego negotiations, it will have adopted a new strategy of ongoing confrontation for protecting its space assets. An era of strenuous competition in space weaponry will have begun, and even if one competitor does, on occasion, enjoy a fleeting advantage, the national security of both rivals will inexorably erode. Any threat to satellites, whether real or potential, will undermine confidence in the ability to deter attack. By the same token, an awareness that satellites are at risk will tend to destabilize a crisis. Even in times of peace, a keen rivalry in the development and testing of ASAT weapons is certain to cause friction, increase suspicions, undermine confidence in the ability to deter attack, and, perhaps, inadvertently spark a conflict.

Finally, the absence of any limitations on ASATs could allow an Anti-Ballistic Missile development program to masquerade as an ASAT program, in order to evade the ban on space-based ABMs of Article V of the ABM Treaty. As stated in that treaty, ballistic missile defense (BMD) undermines the deterrent value of an opponent's ICBM force. Therefore, even a minimal and ineffective BMD capability or an ASAT system that was not intended to have a BMD role, could be misperceived as a serious threat and trigger buildups of offensive missiles.

It does not take great powers of prophesy to predict such an erosion of security, for the analogy with the history of MIRV technology is both instructive and disturbing. In that case, the Soviet Union failed to foresee that the United States would develop MIRVs as a sophisticated response to a primitive ballistic missile defense of Moscow. Neither did the United States anticipate that the strategic benefit that it achieved with MIRVs would eventually boomerang—once the USSR had MIRVed its ICBMs—by putting at risk U.S. silo-based missiles. Today, finally, there is a broad consensus that strategic stability and the cohesion of the Western Alliance would have fared better had the United States abstained from introducing MIRVs. Nevertheless, there is a strange reluctance to recognize that this painful lesson applies directly to current trends in the arms competition in space.

It is in the long-term interest of both superpowers to minimize the likelihood of conflict in space. This is especially true for the United States. Some Soviet satellites do pose a direct threat to certain U.S. military forces, but these threats can be countered without ASATs. The United States, with its forces dispersed around the globe, is more dependent on military satellites than is the Soviet Union. The bulk of Soviet military forces are on or close to the Eurasian land mass, and the Soviets therefore rely primarily on ground-based and airborne communication facilities. Hence, the United States cannot protect its space assets by threatening retaliation against Soviet satellites. The U.S. should, instead, seek to constrain the further evolution of Soviet ASAT capabilities. Such constraints can only be achieved by negotiations that build on the established body of international law represented by the Test Ban Treaty, which forbids nuclear explosions in outer space, the Outer Space Treaty, which bans space-based nuclear weapons and weapons of mass destruction, and the ABM Treaty, which forbids the development, testing, and deployment of space-based ABM systems and protects satellites serving as "national means of verification."

Aside from these considerations that arise from a strictly military conception of national security, political factors of considerable weight also provide a strong incentive for negotiations. In the United Nations General Assembly, the allies of the United States proposed a resolution requesting the U.N. Committee on Disarmament to "consider as a matter of priority the question of negotiating an effective and verifiable agreement to prohibit anti-satellite systems." There is every indication that the Western allies of the United States will, in the U.N. General Assembly, propose that matters move from "considering the question of negotiating" to actual negotiations.

The United States, through its silence on the Soviet proposal, has in effect allowed the Soviet draft treaty to set the agenda for the international discussion of this issue. This is hardly a sound posture for the leader of the Western Alliance, and the world's preeminent military and civilian space power.

Whether the diplomatic and military objectives of the United States are being furthered by current policy has also been questioned by resolutions introduced in the U.S. Senate and House of Representatives calling for negotiations to prohibit the deployment of weapons that can damage or destroy objects in space, and for a moratorium on space testing of such weapons.[5] The recognition that space may become a hazardous no-man's land has also caused apprehension among the commercial users of American satellites.

It is the purpose of this report to examine the feasibility of negotiated limits on anti-satellite weapons. To this end, we shall compare the current status and potential capabilities of the U.S. and Soviet ASAT systems, and assess the military significance of the threat posed by these weapons. We shall find that:

1. The tested Soviet ground-based ASAT presents a rather unreliable, inflexible and ponderous threat to a small number of U.S. satellites in low orbits, but does not threaten high-orbit early warning, navigation and communication satellites essential to the strategic forces;

2. The U.S. ASAT, which is launched by an F-15 aircraft, if it performs according to specifications in impending flight tests, will present a prompt and flexible threat to the majority of Soviet satellites which are in low orbits, and a limited threat to Soviet early warning and communication satellites in highly elliptical orbits;

3. The U.S. ASAT could be modified to threaten satellites in high orbits, whereas the much heavier Soviet ASAT does not appear to be suitable for this purpose.

We therefore conclude that the existing ASAT capabilities do not yet present a serious threat to either superpower at this moment; that it is essential for the security of the United States to restrict the further growth of those capabilities; that negotiations towards that objective are feasible; and that it is urgent to begin such negotiations promptly.

To focus attention on issues that are likely to arise in such negotiations, we put forward an explicit treaty text. In view of our assessment of the current situation and its implications for the future, our draft treaty is, first and foremost, a ban on the testing of ASAT weapons. In essence, THE DRAFT TREATY REQUIRES THAT NO WEAPON THAT CAN DESTROY, DAMAGE, OR CHANGE THE FLIGHT TRAJECTORY OF SPACE OBJECTS, CAN BE TESTED IN SPACE,

OR AGAINST SPACE OBJECTS. Furthermore, the treaty obligates the parties to begin negotiations towards a prohibition on possession of ASATs as soon as the test ban is in place. The proposed text is for a bilateral treaty, because the accession of the Soviet Union and the United States is a prerequisite to a multilateral accord, and because U.S. security depends primarily on constraining Soviet capabilities.

We examine the problem of verifying compliance with such an ASAT test ban, and conclude that the hazards of a totally uninhibited competition in space weaponry are far greater than the potential threat posed by the tightly constrained evolution of ASAT capability that may be possible because of ambiguities in verification. Furthermore, we show that these residual risks can be reduced to an acceptable level by satellite defense measures (such as decoy satellites, maneuverability, etc.) that would cost much less than the program necessary if there were no negotiated constraints. These conclusions show that it is, on the whole, easier to detect violations of the treaty than to determine, in the absence of a treaty, which of an enormous array of permitted space activities pose a security threat.

Finally, on the basis of our findings, we argue that it would be advantageous for the United States to agree to an immediate moratorium on further ASAT space tests, and that the security of the United States would not be in jeopardy should such negotiations fail, or should a treaty be abrogated or circumvented by the Soviet Union.

2. CURRENT U.S. AND SOVIET SPACE ASSETS AND ASAT SYSTEMS

Negotiations towards restraints on further ASAT development must take into account the existing balance in U.S. and Soviet space assets and military capabilities.

SATELLITES

Since U.S. forces are spread across the globe, secure long-range communications are essential to U.S. security. For that reason, more than 60 percent of long-haul military communications are now transmitted via satellites, and that percentage is growing. There are no facilities on the earth's surface that provide a satisfactory replacement for this satellite system.

The Soviet Union's military forces are mainly on or near to the Eurasian land mass, and can readily communicate by using a large variety of ground-based and airborne facilities, in addition to satellites. Indeed, one can say that the Soviet Union uses its satellites as a back-up for its ground-based and airborne communications and intelligence gathering systems, while the converse is true of the United States.

The vulnerability of a satellite to attack is largely determined by the nature of its orbit. These fall into several categories: geosynchronous orbits, in which the satellite is stationary above a point on the the earth's equator at an altitude of about 22,000 miles; semi-synchronous orbits, with altitudes of about 12,000 miles; and low-earth orbits, at altitudes up to about 1000 miles. Satellites can also be in highly elliptical orbits that dip as low as several hundred miles and rise as high as geosynchronous orbits. Some U.S. satellites are in orbits that are considerably higher than geosynchronous orbits.

Tables 1 and 2 (Appendix III) provide an overview of the orbital characteristics, endurance, and missions of the major U.S. and Soviet satellite networks.[6-15]

U.S. satellites are considerably more sophisticated, more reliable, and far more long-lived than Soviet satellites. For example, the Soviet Union has only recently begun to retrieve high resolution film capsules without returning the satellite to ground, a technique that the U.S. has been using since the early 1960s. It is only within the last few years that the Soviets have been able to bring their early warning satellites to operational status.[7,15] Despite a large commitment to ocean surveillance from space, malfunctions reportedly prevented Soviet satellites from monitoring the Falkland war.[7]

U.S. Defense Department publications[16] claim that the Soviets have a much larger space program than the U.S., and cite the far larger number of Soviet launches and the payload placed into orbit as evidence for this claim. But the disparity in launch frequency is entirely accounted for by the much shorter life span of Soviet satellites, or by the need to retrieve the satellite itself.[6] Of the 101 Soviet satellites launched during 1982, over 50 percent were no longer in orbit or were out of operation by year's end.[7] Figure 1 documents this assertion in detail for the case of photo reconnaisance,[9] where Soviet satellites typically stay aloft for two weeks, while U.S. KH-11 satellites stay up for more than two years. Furthermore, a comparison of gross weight placed into orbit should not include the weight of the Shuttle orbiter; two Shuttle flights exceed the 660,000 lbs. annually put into orbit by the U.S.S.R.

The notion that the scope of the Soviet space program can be gauged by estimates of the Soviet space budget should also be treated with caution; if such a comparison were made in agriculture, it would lead to the conclusion that the Soviet Union has a more potent food-producing industry than the United States.

ASATs

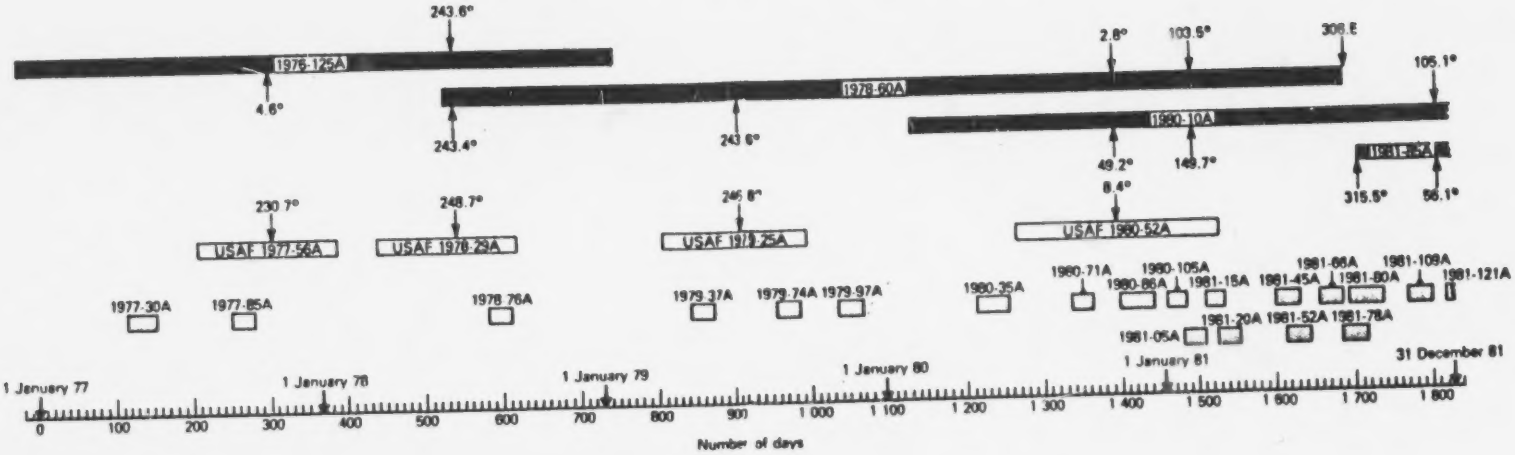
The existing Soviet ASAT interceptor weighs three tons (See Fig.2). It is launched by the ground-based SS-9 booster (the very large predecessor of the current SS-18 ICBM booster) into an orbit close to that of its target. The interceptor then crosses the path of its target after one or two orbital revolutions, whereupon its non-nuclear warhead explodes, and the resultant shrapnel destroys the target satellite. All Soviet tests have used launchers at Tyuratam in Kazakhstan, and orbits within a very narrow range of inclinations (62 to 65 degrees).

The highest altitude reached thus far by the Soviet interceptor is reported to be about 1400 miles. Since the Soviet ASAT is ground-based, any particular weapon must wait up to 24 hours until the earth turns to bring the prey's orbit above the launch site.

It would appear to be very difficult to modify the Soviet system in order to threaten targets in high orbits. If it were to reach a satellite in geosynchronous orbit, it would have to be given an additional velocity of four kilometers per second, which would require an additional stage of propulsion about four times larger than the enormous booster that it already uses to reach low orbits. Therefore, the current Soviet system only threatens low-orbit space objects. About a third of all U.S. satellites fall into this category, and their most important national security functions are photographic and electronic surveillance of the earth's surface. U.S. satellites responsible for early warning, nuclear attack assessment, additional electronic intelligence, and military communications are in very high orbits, and are not vulnerable to the current Soviet ASAT.

FIGURE 1

COVERAGE BY U.S. AND SOVIET LONG-LIVED PHOTOGRAPHIC RECONNAISSANCE SATELLITES LAUNCHED DURING 1977-81



US KH-11 satellites

US Big Bird satellites

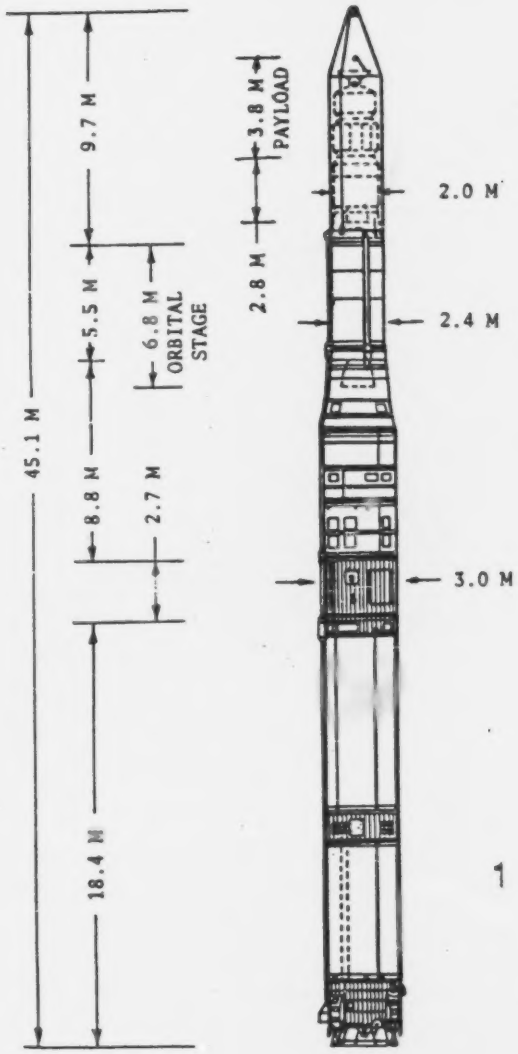
Soviet Cosmos satellites

Each block represents a satellite; the beginning of each block corresponds to the date on which the satellite was launched and the length of the block corresponds to the lifetime of the satellite in days. Values of Ω are indicated in degrees.

CREDIT: SIPRI

FIGURE 2

SOVIET ASAT



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NOTE: THE F-1M BOOSTER HAS NOT BEEN DISPLAYED. DETAILED BOOSTER CONFIGURATION IS CONCEPTUAL ONLY.

The U.S. ASAT system is based on quite different principles: it is not designed to go into orbit, but to intercept its quarry by "direct ascent," a far more difficult approach requiring extreme accuracy in position and time. The interceptor is the so-called Miniature Homing Vehicle (MHV), which is carried into space on a two-stage rocket that in turn is launched from a high altitude F-15 fighter plane (Figure 3). The MHV is a small cylinder with a diameter of about one foot that seeks its target by a combination of infrared telescopes, a laser gyroscope, and a set of small jets that can alter its trajectory (Figure 4). It destroys by direct impact at very high velocity.

Because it is plane-borne, the U.S. ASAT is, in principle, able to operate from any airbase that has adequate communication facilities. Interception of satellites in low orbits could take place within an hour if enough F-15s were suitably dispersed. The U.S. ASAT could not, however, be used to destroy the Soviet ASAT itself. Tethered decoys could readily be attached to the Soviet ASAT for the duration of its flight. In its present form the MHV cannot reach geosynchronous satellites, but this is not of great consequence at this time, because almost all Soviet satellites are in low or highly elliptical orbits.

By using a three stage booster, the U.S. ASAT should be able to reach geosynchronous targets. The whole system would weigh some 16,000 lbs., and could still be carried on an F-15.

The Soviet ASAT has been tested some twenty times since 1968. In the first test series (1968-1971), radar homing was used to approach the target, and the success rate was quite high (approximately 70 percent). Later tests used either a more sophisticated homing device, or a "pop-up" maneuver intended to provide a quick approach to the target. Both aspects of these tests were almost uniformly unsuccessful.[7]

Launches of the U.S. interceptor from an F-15 to a point in space are scheduled for later this summer, but tests against space targets are not scheduled until late in 1983 or early 1984.

These facts allow us to draw up a current balance sheet:

• The Soviet ASAT system is deemed to be operational by the U.S. Department of Defense on the basis of the 1968-71 tests, whereas the U.S. system is now ready for flight testing.

• The Soviet Union has most of its space-based assets in low earth (LEO) orbits, while the U.S. has many of its most important satellites in geosynchronous (GEO) orbits.

• The Soviet ASAT can only attack targets in low-earth orbits, and would require a very large booster to carry it up to geosynchronous targets (see Section 5

below). The U.S. interceptor could, with a three-stage booster, reach geosynchronous targets.

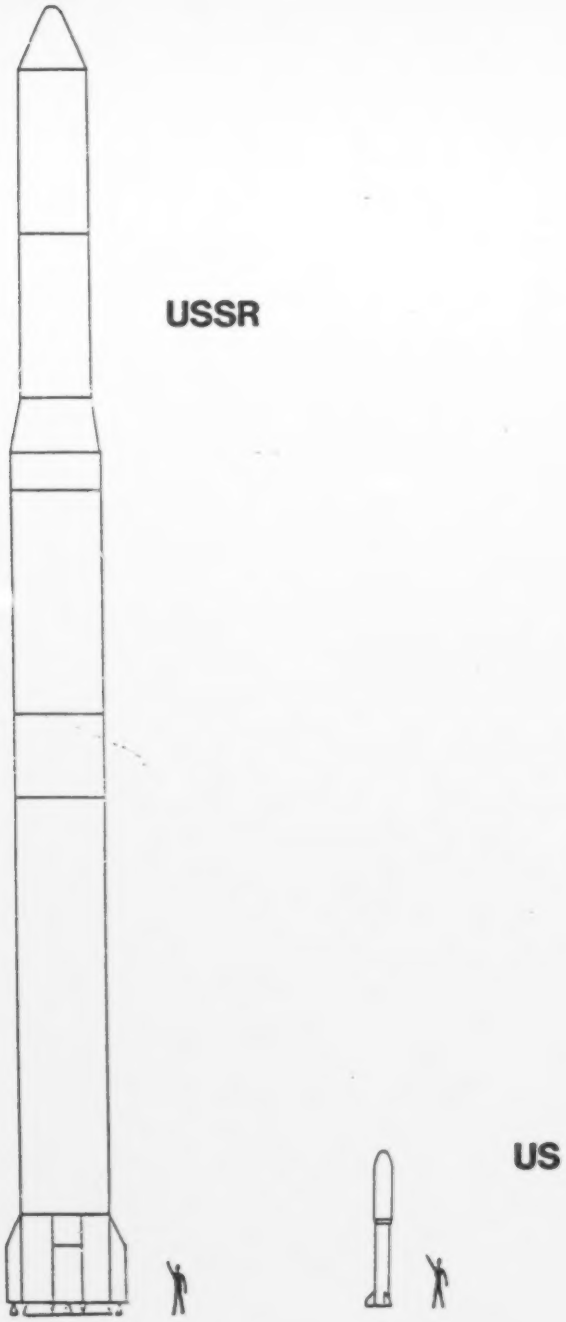
• The Soviet ASAT, which uses fixed launch sites, is a cumbersome and inflexible system in comparison to the mobile, F-15 based U.S. system.

These comparisons lie behind our contention that the United States risks little if both nations' ASAT development programs were to be suspended at this time, while negotiations take place. If, for one reason or another, the United States would find it necessary to resume its development program, it could begin space tests promptly to bring its ASAT system up to operational standards. The Soviet ASAT system, though it is deemed to be operational, only poses a rather clumsy threat to a portion of U.S. space systems, and it has little potential for attacking the warning, communication, and navigation satellites on which U.S. strategic forces depend.

In short, if negotiations fail, or arms control in space were to break down, the United States would not find itself in a disadvantageous position.

FIGURE 5

COMPARISON OF U.S. AND SOVIET ASATS



3. A TREATY LIMITING ASAT WEAPONS

The full text of the treaty put forward here is to be found in Appendix I. Here we shall summarize the goals this treaty sets out to achieve. The differences between our proposal and the 1981 Soviet draft treaty are discussed briefly here, and are analyzed more fully in Section 7.

The proposed treaty has three essential ingredients:

• The signatories would undertake not to destroy, damage, render inoperable or change the flight trajectories of space objects.[17]

• The signatories would undertake not to test in space or against space objects weapons for destroying, damaging, rendering inoperable, or changing the flight trajectories of space objects. Furthermore, the signatories would undertake not to place such weapons in orbit or to station them on celestial bodies or in outer space in any other manner.

• Compliance would be verified by national technical means, enhanced by cooperative measures and buttressed by collateral constraints on other space activities to prevent circumvention of the treaty's provisions.

The treaty proposed here formulates restrictions and prohibitions in general terms. Excessive detail in an arms control accord may inadvertently leave loopholes and convey the impression that activities and weapons not explicitly prohibited are therefore permitted. A treaty weighted down with excessive detail may also prove inflexible in coping with new circumstances, and unanticipated technological developments. Our purpose in presenting general treaty provisions here is to provide a focus for discussion of feasible and desirable restrictions on ASAT weapons. In actual bilateral negotiations, the U.S. and the Soviet Union could incorporate more detailed language into the final treaty text that reflects the best advice and wisdom that consultations within each government would provide.

The text put forward here is for a bilateral treaty. However, once agreement between the U.S. and Soviet Union is reached, a multilateral accord open to all nations would be desirable.

We note that our proposal is not the most comprehensive limitation on space weapons possible, for a treaty could also forbid any possession of such weapons, and require that those already constructed be dismantled or destroyed. Such a comprehensive ban is what the United States evidently sought in the negotiations of 1978-1979.

There is much to be said in favor of such a comprehensive ban, but it also

poses formidable verification problems that could only be resolved by protracted negotiations. The major difficulty in a ban on possession would probably come from the U.S. F-15/ASAT, which is small (see Fig. 3). Intrusive on-site inspection would be required to verify that it is not deployed unless the Soviet Union were to be satisfied that they could acquire this knowledge by other means. While the large size (see Fig. 2) of the Soviet ASAT would make the dismantling of the launchers used in past tests readily observable, it is not clear whether other launchers used in the Soviet space program could substitute for this purpose.

To avert further arms competition in outer space as promptly as possible, a ban on further tests in space of ASAT weapons must take priority, and the proposed treaty addresses itself to this urgent objective. Subsequent negotiations that face the knotty problems of verifying a more comprehensive ASAT ban could then be pursued in an atmosphere free of the tensions that would be created by a simultaneous competition in space weaponry. For that reason, the draft treaty obligates the parties (Article V) to begin active negotiations towards more comprehensive restrictions on space weapons as soon as the test ban is in place.

In contrast to the 1981 Soviet draft treaty, which only speaks of weapons in orbit, the treaty proposed here does not allow the use or testing of ASAT weapons whether they are ground- or space-based. Furthermore, our proposed treaty forbids the parties from destroying any space objects (including one's own), whereas the Soviet draft only forbids attacks on space objects of other states. Indeed, the Soviet draft treaty does not appear to limit further testing or development of the current Soviet or U.S. ASAT systems. In space tests, the Soviet interceptor goes into earth orbit before attacking its target. But it may well be able to attack satellites by direct ascent from the ground, or after only a partial earth orbit, and thus it may elude a ban on weapons "placed in orbit." The U.S. ASAT system uses a direct-ascent interceptor and never goes into earth orbit.

A ban on the use and testing in space of ASAT weapons cannot by itself protect satellites. Nevertheless, the ban on testing would provide a severe impediment to the further development of ever more capable ASAT weapons. For the foreseeable future the military and civilian branches of the United States government are likely to remain at least as vitally dependent on satellites as they are already. It is therefore in the long-term security interest of the United States to enhance the survival of its space assets as much as possible, and to achieve this goal with as little friction and cost as it can.

4. THE RELATIONSHIP BETWEEN ASAT AND ABM

Two aspects of the relationship between anti-satellite weapons and ballistic missile defense are of relevance here. First, what restrictions does the SALT I ABM Treaty of 1972 impose on the evolution of technologies that have an ASAT or ABM potential? Second, what is the relationship between the technologies themselves?

It has always been the position of the United States that the ABM Treaty forbids the development, testing and deployment of ABM systems, or their components, except for one system with specified equipment deployed at each nation's capital, and one system deployed in the vicinity of one ICBM field in each country. (The 1974 Protocol reduced this to one system for each side.) The most recent enunciation of this position is to be found in the President's 1984 Fiscal Year Arms Control Impact Statement,[18] which appeared in April 1983, and contains the following statements:

(a) "The ABM Treaty bans the development, testing and deployment of all ABM systems and components that are sea-based, air-based, space-based, or mobile land-based."

(b) "The ABM Treaty prohibition on development, testing and deployment of space-based ABM systems, or components for such systems, applies to directed energy [lasers and particle beams] technology (or any technology) used for this purpose. Thus, when such directed energy programs enter the field testing phase they become constrained by these ABM Treaty obligations."

(c) "The ballistic missile defense potential of future directed energy weapons could eventually create a conflict with the obligations assumed by the U.S. under the provisions of the ABM Treaty."

(d) "With regard to directed energy systems in an ASAT role, only the actual use of systems to interfere with national technical means used to verify compliance with strategic arms control agreements—as opposed to development, testing, or deployment of systems that could be used in such roles—is prohibited under the provisions of the ABM Treaty and the SALT I Interim Agreement and Article XV of the unratified SALT II Agreement."

In short, the ABM Treaty places severe restrictions on any weapons program that is considered to have an ABM role, whatever its physical principles or technology. On the other hand, the treaty has only a minimal impact on ASAT programs, because it only forbids interference with satellites that are used to verify strategic arms control accords.

The lack of stronger restrictions on ASATs provides a possible loophole in the ABM Treaty, since it allows claims that a weapons system under development is intended to be an ASAT when the real objective is ballistic missile defense. Satellites are much more fragile than missiles, and since their time in space is measured in months or years, instead of minutes, they are also far easier to target. As a result, virtually any putative BMD system will be an effective ASAT long before it achieves any significant ABM capability, and the claim that it is really only an ASAT may be difficult to refute for many years. By the same token, a program that really is intended only to achieve an ASAT capability may be perceived as a nascent BMD by the other side.

That these are not just academic concerns is illustrated by the U.S. ASAT. The Miniature Homing Vehicle exploits a technology first developed by the U.S. Army for its Homing Overlay project, which explores the feasibility of intercepting ICBMs in mid-course as the second tier of a comprehensive BMD system.[19]

To summarize, the deployment of ASATs could trigger buildups of offensive missiles, which is precisely what the ABM Treaty was designed to prevent.

5. THE ASAT THREAT WITH AND WITHOUT A TREATY

The value of a ban on ASAT space tests is best measured by looking ahead to the variety of ASAT threats that can be expected in the next five to ten years if there are no further restraints on weapons competition in outer space. In that period the total number of American satellites will increase to about 100, with approximately one-third of these in low earth orbits, about one-fifth in semi-synchronous orbits, and about one-third in geosynchronous orbits. The others will be in highly-elliptical orbits that may dip as low as several hundred miles, but may also rise as high as geosynchronous orbits.

If the Soviets are free to continue ASAT development, we may anticipate the following course of space weapons competition. The first Soviet move might be to improve their current interceptor to reach higher altitudes and defeat potential U.S. satellite defense measures, such as radar jammers, decoys, and evasion. Tests of the current Soviet interceptor up to geosynchronous orbits might be feasible within relatively few years, if the Soviets set themselves to it. This would mean matching the interceptor to a new booster, such as the liquid-fueled PROTON or A-2 rockets used to place the Salyut and Soyuz space vehicles into orbit. The whole system would require testing against space targets to confirm that it worked, and the long launch preparations needed for such massive boosters would make this a very cumbersome ASAT.

Alternatively, the Soviets could pursue a more promising ASAT development program along one or more of at least three paths: a more agile miniature ASAT interceptor, such as the U.S. is developing, which could reach all altitudes with smaller boosters; a more exotic orbiting laser ASAT; or space mines. A space mine is a small satellite that carries an explosive charge and is placed in an orbit that closely follows its potential target. It could then be commanded to destroy instantly the satellite it has accompanied for weeks or months. Unless negotiated restrictions are placed on ASATs, it is very likely that space mines will soon pose a critical threat to satellite systems in conventional war or at the outbreak of nuclear war.

Debate persists over the feasibility and cost of space-based lasers, but there is no question that both sides are vigorously developing them. According to Air Force Chief of Research and Development, General Kelley Burke, the Soviets are believed capable of launching a laser ASAT of limited effectiveness within five years, and a more effective system perhaps in the 1990s. In keeping with their accustomed practice, the Soviets may well develop and deploy a mix of ASAT weapons, each posing a different threat to U.S. satellites: improved ground-based interceptors and lasers for lower orbit attacks, space-based lasers for higher orbits, and space mines for geosynchronous attacks. Along the way, the number of launch sites would be increased, inventories of ready-to-fire ASAT weapons

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would multiply, and all U.S. satellites would become progressively more vulnerable to attack.

The U.S. has already mapped out its initial moves in this competition. In the beginning, it will incorporate defenses on satellites, and deploy the sophisticated F-15 ASAT MHV interceptor described in Section 2. Ground- and air-based lasers would provide additional ASAT capability against low-orbit satellites while helping to solve technical problems in the development of space-based lasers. A "defensive" space-based laser weapon would be the next step—an ASAT deployed to attack Soviet ASATs. At this stage, the scene might recall the battleship competitions of an earlier era, as each side strives for the competitive edge of just a bit more firepower, longer range, thicker armor, and larger fleets.

Under such unrestrained ASAT competition, the advantage will almost certainly go to the offense. A duel between a sophisticated ASAT weapon devised for the sole task of killing, and a satellite built for other purposes and only incidentally equipped to defend itself, will always be a mismatch. Moreover, U.S. satellites are designed for lifetimes of five to ten years, so the defenses they carry with them into space on the day of launch stand a good chance of being nullified by a rapidly-changing ASAT environment. Soviet satellites have much shorter lifetimes, are therefore more frequently replaced, and could be more readily modified to counter U.S. ASAT developments.

In confrontations in a world filled with ASATs, fear of a preemptive strike will run high, and the very process of unlimbering ASATs for possible use would drive tensions higher. Since attacks on satellites would be a possible opening step in war, even inadvertent events in space may be mistaken as a signal that war has begun. The sheer multiplicity of ASATs would also raise the likelihood of such an inadvertent occurrence. Such events have happened. For example, in 1975 there was concern that U.S. early-warning satellites had been attacked by Soviet infrared lasers; later it was established that these satellites had only observed infrared radiation from a Soviet natural gas pipeline fire.

Were a satisfactory ASAT arms control agreement in force, the future would look quite different. As matters stand now, only a fraction of U.S. satellites are exposed to the rudimentary Soviet ASAT system. Under a general ban on tests of ASAT systems in space, Soviet efforts to improve their current interceptor or to devise a new one should be blunted. Tests or use of lasers or high-powered transmitters to damage satellite sensors or to burn out satellite receivers would be banned. In contrast, under unrestrained ASAT competition, protecting American satellites through hardening, maneuvering, deception, and so forth, against ever more sophisticated and nimble Soviet ASATs, will become untenable. Exotic laser ASATs may well prove infeasible in the near future, but the Soviets would still be free to duplicate the U.S. miniature ASAT interceptor and threaten American satellites at all altitudes. Five to ten years from now, after successive rounds of unrestrained competition, the security of U.S. satellites, and thereby of the

United States, will have been seriously impaired, despite greatly increased expenditures. In sum, the contrast between a future with ASAT arms control, and one without, is stark.

It is to be hoped that an initial ban on ASAT tests could soon be augmented by a wider agreement to dismantle ASATs. Until such time as a comprehensive ban on possession of ASAT systems could be negotiated, there would still be a limited Soviet ASAT threat to those U.S. satellites within reach of the current Soviet interceptor. It would be doing arms control a disservice to claim that ASAT arms control alone could protect all space assets. (By the same token, extravagant claims that acquiring ASAT weapons will solve all our problems are equally mistaken.) What ASAT limitations could do is to make the task of protecting satellites less difficult, more reliable, and thus enhance confidence in the survival of satellites vital to U.S. security. ASAT arms control, then, serves American security interests by being an indispensable adjunct to, and not a replacement for, U.S. programs to diversify its satellite functions and harden its satellites against attacks.

Under a general ban on space tests of ASATs, the U.S. would also have to forego tests in space of the ASAT interceptor it is now developing. The U.S. reportedly is set to begin tests of its interceptor in space and against space targets within the year. If an ASAT accord were reached promptly, or if the U.S. offered to improve the prospects for successful negotiations by a voluntary test moratorium, the outcome might be that the U.S. would have no test experience with its ASAT in space, while the Soviets would have conducted some twenty tests over the past fifteen years. But there are compensations that must be weighed. The Soviet's ASAT test program has not been a great success (see Section 3). The U.S. has already accumulated a body of test and engineering experience just short of tests in space, so it would not be left with a blank slate. Furthermore, unless the U.S. closes off further ASAT testing soon, it risks exposing all its vital satellites to possible improvements in the Soviet ASAT system, improvements that might require years of American effort and billions of dollars to then offset.

In agreeing not to use ASATs, the U.S. would also forego one of the stated purposes for buying its ASAT system: attacking Soviet satellites that can be used to target U.S. military forces. The principal satellites of concern are the Soviet Radar Ocean Reconnaissance Satellites (RORSATs) and Electronic Ocean Reconnaissance Satellites (EORSATs) that can locate ships at sea. It is important to weigh whether this limitation would significantly compromise American security.

To begin with, giving up ASATs does not mean giving up all means of countering Soviet satellite capability. Nothing in the treaty proposed here would prevent U.S. forces from using other countermeasures to deceive or confuse Soviet satellites, such as spoofings, decoys, camouflage, electronic countermeasures, etc.

Secondly, ASATs may not in fact provide much protection for U.S. military forces. The Soviets have a variety of sea-based and airborne reconnaissance and targeting systems, so shooting down Soviet satellites would not eliminate the threat. Any U.S. forces designed to operate along the periphery of the Soviet Union, where U.S. alliance obligations are, must be equipped with an array of countermeasures and defenses in any case. Thirdly, if the Soviets are the ones to initiate hostilities, they will have been able to gather and pass along satellite information needed to target U.S. forces before conflict starts. The U.S. would be unlikely to shoot down Soviet satellites preemptively just on suspicion of Soviet intentions; doing so would certainly provoke hostilities. And for some time after hostilities break out, the Soviets may also be able to launch new satellites to replace those destroyed by a U.S. ASAT; American military forces would again have to be prepared to fend for themselves in the face of threatening Soviet satellites.

Finally, U.S. military forces (with the exception of submarines) cannot count indefinitely upon concealment for their survival. They must be prepared sooner or later to withstand the brunt of Soviet forces. A U.S. ASAT system cannot protect an aircraft carrier, once it is discovered, by shooting down Soviet anti-ship missiles or intercepting torpedoes. But the U.S. ASAT program diverts resources and funds from other defense programs vital to our forces. According to the General Accounting Office, the U.S. ASAT program is already slated to cost $3.6 billion; the GAO argues that the cost could well rise to "tens of billions." Even at $3.6 billion, the "opportunity cost" of the ASAT system already equals one Nimitz-class nuclear-powered aircraft carrier. Where such trade-offs are involved, an ASAT system is not an incidental option, but potentially a major drain upon overall U.S. military preparedness.

The most important concern for the U.S. is to ensure that its satellites can carry out their tasks, even in crisis or conflict. Using an ASAT to shoot down Soviet satellites would not protect or restore U.S. satellites. It is occasionally argued, as justification for the U.S. ASAT program, that our own ASAT can deter Soviet ASAT attacks by the threat of a tit-for-tat response. Given the greater American dependence upon satellites, the U.S. might in fact only make its situation worse by such tit-for-tat exchange. The best "deterrent" to Soviet ASAT attacks is Soviet awareness that U.S. satellite functions are diversified and hardened, and adequately supplemented by non-satellite systems, so that an attack on satellites would not succeed in crippling the overall U.S. military capability. An American ASAT system contributes nothing to this "deterrent"; it promises only to divert funds from the countermeasures that would genuinely provide such security.

6. VERIFICATION AND RESIDUAL RISKS

It has been argued that ASAT arms control poses daunting, perhaps even insuperable, verification problems, more so than any other area of arms control. One reason offered for this is that space satellites are so few in number, and their unique capabilities so difficult to duplicate with ground-based alternatives, that even a few ASAT weapons covertly acquired in violation of an agreement could reward the cheater with significant military advantage in a conflict. It is additionally argued that any limitations upon weapons or space programs that would be comprehensive enough to close off such cheating would necessarily be so stringent that they would preclude many civilian uses of outer space. As an illustration, the Soviet Progrez resupply vehicles, used with the Salyut program, obviously have features in common with ASAT interceptors: they can be launched to the vicinity of an orbiting satellite, maneuvered alongside, and brought into contact. Yet banning them, or limiting all such maneuvering space vehicles to prevent them from being configured as ASAT weapons would impair not only the Salyut program but the U.S. Space Shuttle as well. The problems are multiplied if we also consider the ASAT potential of other weapons not specifically designed as ASATs, such as ground-based ABM interceptor missiles, or nuclear-tipped ICBMs, or exotic directed-energy air defenses.

These arguments point to genuine concerns the U.S. ought to have about the survivability of its satellites. At the same time, these arguments assume that the future is dictated by past errors. In the past, the U.S. coped with limited budgets and high launching costs (hundreds, even thousands of dollars per pound to place objects in orbit) by relying on relatively few, long-lived, equipment-crammed satellites to perform vital military tasks. Little effort was made to incorporate survivability measures or to diversify functions. Because of their design and budgeting constraints, U.S. satellites are even vulnerable to primitive ASAT weapons.

But with or without ASAT arms control, the U.S. cannot go on like this. Nor does it intend to. A Presidential Directive in May 1978 ordered that all future U.S. military satellites be equipped with survivability measures and devices for detecting ASAT attacks. Some satellites probably cannot be protected from attacks at any affordable cost (e.g., large and fragile low-orbit satellites); and some attacks may work against almost any satellite (e.g., nuclear warheads detonated near a satellite). The best approach to reducing the risk is to move to a larger number of simpler, more easily replaced satellites that are more readily confused with decoys. Yet even this technique will succeed only if the Soviets are prevented from developing a cheap, nimble ASAT system capable of promptly attacking great numbers of satellites. It is precisely this sort of development that an ASAT arms control agreement should prevent.

There are several verification tasks that must be tackled under a general ban

on ASAT weapons tests and use. The U.S. would have to confirm that the existing Soviet ASAT interceptor was not being tested in space; that no new ASAT weapons were being devised and tested in space or against space targets, including such new exotic ASATs as ground- or air-based lasers that could be aimed at low-orbit satellites; that weapons originally designed and deployed for other missions were not being tested in an ASAT mode and that non-weapon space vehicles and programs were not posing significant ASAT threats.

The U.S. already has a diverse array of intelligence and space surveillance facilities for keeping track of Soviet activities, and this array is being expanded. NORAD's Space Object Catalogue is constantly being updated to record the identity and current orbits of all space objects (several thousand in all, of which several hundred are active or defunct satellites). NORAD's space tracking radar network has recently been upgraded to provide greater tracking accuracy, and gaps in the network have been closed by installing and improving radars in the Pacific. The GEODSS (Ground-based Electro-Optical Deep Space Surveillance) system, when completed in 1987, will augment ground radars and provide precise, highly-detailed optical and orbital signature data on man-made objects approximately 3000 miles from earth and beyond. Upgraded radars in the United States, Turkey, and Kwajalein will provide additional tracking of objects in geosynchronous orbits.

Other electronic and optical sensors deployed around and over the Soviet Union add to U.S. ability to detect and classify Soviet missile and space launches. The potential for monitoring activities **in** outer space **from** space must also be considered. The recent demonstration of what is possible, in inspecting damaged and missing thermal tiles on the first Space Shuttle flight in April 1981, hints at what might be routinely feasible. On occasion, critiques of space verification capabilities tend to match only **current** monitoring capacities against **future** conceivable but nonexistent ASAT weapons, and not surprisingly, these comparisons come to pessimistic conclusions. More imaginative evaluations should consider what we could now do but have not funded, as well as potential innovations in monitoring capabilities. In particular, under a treaty-restricted regime it would become worthwhile to make specialized observation systems to monitor the infrared emission from Soviet satellites in order to determine whether they were being heated by ground-based or airborne lasers, to provide close-in photographs of maneuverable space objects, and the like.

The effectiveness of all the monitoring facilities would be enhanced under an arms control agreement by provisions, such as those included in prior accords, prohibiting interference with national technical means of verification and deliberate concealment that impedes verification. Since the Soviets have already agreed in principle that arms control accords may include cooperative measures contributing to the effectiveness of verification by national technical means (in the SALT II Joint Statement of Principles), these too should be exploited to improve confidence in verification.

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The U.S. already has long monitoring experience with tests of the current Soviet ASAT interceptor, going back 15 years. Covert tests of that weapon would be rather risky for the Soviets. Conceivably, the Soviets might try to test their current ASAT covertly in some radically different manner that expanded its capabilities, e.g., on a new booster capable of intercepts significantly higher than its present ceiling. This would not be a "nimble" threat, even in the unlikely event that cheating succeeded. The booster required to loft the Soviet's bulky ASAT up to geosynchronous altitudes would have to be comparable to the large U.S. Saturn IB or the Soviet PROTON booster, massive rockets with long preparation times, whose launches would be unmistakable.

More likely, if the Soviets hoped to expand their ASAT capability covertly, they would attempt an entirely new weapon, such as a miniature homing ASAT, or a more exotic laser ASAT, or space mines. Until such time as ASATs are banned altogether, neither side would be violating the limitations if they devised such systems on the ground; they would be banned from testing them in space or against space objects.

But the technological challenges in building an effective space-based laser ASAT are formidable, even if unrestricted testing in space were permitted, and doing it all covertly would certainly be a protracted, highly risky task. To prevent the Soviets from testing ASATs in space under the pretense of developing, for instance, a space-based laser anti-aircraft defense system, our draft treaty also bans space weapons for damaging or destroying objects in the atmosphere or on the ground. This prohibition would also reinforce existing limitations on space weapons in the 1967 Outer Space Treaty and the 1972 ABM Treaty.

Ground- or air-based laser ASATs are far easier to construct than space-based lasers, but it is not clear that they offer any advantages over current ASATs. Such lasers could impair unprotected satellite sensors at high altitudes, but could only destroy satellites in low orbits. Whether Soviet technology is sufficiently far advanced to make a miniature homing ASAT feasible in the near term is not clear. In all these new ASATs, however, very high accuracies in homing or aiming would be necessary, and these would be difficult to confirm without actual tests against space targets. Such tests would leave a host of telltale signs: launch of the ASAT itself; a large flow of data from the test vehicles that the Soviets would have to transmit; damage to the target that causes it to fragment or tumble; intense heating that can be detected by infrared sensors; and displacement of the target's orbit. While the Soviets were pressing ahead with such innovations, there would, of course, be a parallel expansion and evolution of U.S. monitoring facilities, which would further facilitate the detection of cheating.

Space mines placed in orbit near targets and detonated only when conflict begins are another problem. They seem ingeniously simple. The technology could perhaps be fairly primitive, and if the only tests required were triggering the explosive upon command, they could be amply tested on earth. Nevertheless, if

covertly deployed they might give themselves away or pose only a manageable threat. The orbital paths of satellites are not necessarily stable, especially those of satellites in lower orbits that are subject to atmospheric drag, or that maneuver to perform their missions. Space mines dogging along behind such maneuvering satellites would be bound to raise suspicions, and the mine ceases to be such a simple device if it must be equipped with homing and maneuvering capabilities to keep track of its potential target or be able to close in rapidly on command. At geosynchronous altitudes, where all orbits are more stable, a space mine skulking near its target could still arouse suspicions, since all legitimate satellites are supposed to be registered (under the 1975 Convention on Registration of Objects Launched into Outer Space) and are to maintain minimum separation distances in geosynchronous orbits. Again, a space mine becomes a complex device if it must pretend to be something benign when far away from its target to avoid suspicions, yet can swiftly seek its target upon command.

When it comes to verifying that non-ASAT weapons are not being put to ASAT purposes, long U.S. experience at monitoring the characteristic patterns of Soviet ICBM and ABM tests would also make it risky for the Soviets to test these weapons in an ASAT mode. Of course, even in the absence of tests such weapons would still have to be taken into account as an ASAT threat, since the great kill-distance of nuclear explosions in space could compensate for deficiencies in guidance systems or test experience. But it is also true that present ABM interceptors can reach satellites only in the lowest orbits, and any nuclear explosion in space carries a grave risk of escalation, of damage to "friendly" satellites as well as to the target, and of uncertain Electro-Magnetic Pulse (EMP) effects upon other military and civilian systems on earth. While such residual ASAT threats are less awesome than what unrestricted ASAT competition would produce, they would persist, even if the ability to verify a test ban were perfect. They call for continuing satellite survivability programs as an adjunct to ASAT arms control.

Some non-weapon space vehicles may also have inherent ASAT capability (e.g., resupply vehicles that can home in on other satellites), and the U.S. would want to verify that such vehicles were not being tested in an ASAT mode. The overlap of non-weapon space technology with ASAT missions should not be exaggerated, however. The continuing high cost of launching anything into space will certainly force designers to optimize space vehicles for their specific non-weapon missions, and the result is not likely to be a very agile or capable ASAT. The Soviet's Progrez resupply vehicle, for instance, is obviously designed to deliver the maximum amount of provisions in few trips. Its takeoff weight, fully loaded, is perhaps three times that of the Soviet's own bulky ASAT, and consequently it uses an enormous booster just to reach altitudes of a few hundred miles. Such jury-rigged ASATs are not very good foundations for a weapon system to "sweep the skies," and making vital U.S. satellite functions survivable against such residual threats should be manageable.

Nevertheless, an ASAT arms control agreement could incorporate collateral

constraints on the characteristics and use of non-weapon space technologies. These constraints might include, for instance, limits upon speed of approach in rendezvous maneuvers, or upon power/aperture characteristics of lasers in space. However, it would be premature now to propose a long list to govern future changes in space technology. The treaty proposed here would accomodate such collateral constraints in several ways. Cases that the parties find of immediate concern could be addressed in treaty negotiations and incorporated as additional articles, or perhaps as cooperative measures in test or space-use procedures that aid verification. Limits on future cases involving new technologies would best be addressed on a case-by-case basis in the Standing Consultative Commission, as the specific dimensions of problems and remedies become clear. This approach would raise our confidence that such space vehicles were not being readied as ASATs, while minimizing the impact upon non-weapon space exploration.

A final verification concern is that of "breakout," that is, the possibility that the Soviet Union could assemble a significant ASAT capability by abruptly running a quick set of space tests (and thus abrogating the treaty). At issue here is how close to operational status an ASAT weapon could be brought, if assembled and tested only on the ground or covertly in space as dismantled components—e.g., testing homing sensors for ASAT interceptors on some ostensibly non-weapon space mission. Inconsistencies occasionally crop up in arguments on this matter. On the one hand, it is claimed the Soviets could readily concoct an ASAT system even though space tests were banned; on the other, it is asserted the U.S. could not accept a ban on testing because it would then be unable to confirm that its own ASAT system works. A more balanced viewpoint is in order here.

The U.S. has already conducted enough engineering tests of its own ASAT interceptor to be ready for immediate space tests, so even if a moratorium on tests were agreed upon now, the U.S. would not be without experience. If the ASAT accord banned tests but allowed both sides to keep their present ASAT weapons, then clearly both would have some "breakout" potential. Though the existing Soviet ASAT is a much more tractable problem than what unrestrained ASAT competition would bring, this "breakout" potential would be of some concern for the U.S. A combination of reasonable survivability measures, eroding Soviet confidence in their ASAT in the absence of tests, and further negotiations leading toward complete dismantling of ASATs would address our concerns.

"Breakout" using an entirely new ASAT weapon that had been tested only on the ground or covertly—component by component—in space would be quite risky, technically and politically. In ASAT weapons as in modern weaponry in general, capability and complexity are linked—the more capable a weapon is in coping with a variety of combat requirements, the more complicated it is likely to be, and the more in need of tests that simulate actual engagements. Soviet attempts to conduct realistic full-system ASAT tests in space covertly would confront the whole battery of U.S. intelligence sensors. On the other hand, breaking the ASAT system down into component parts for covert testing, in order

to minimize the chance of detection, entails a risk that the whole system will not work as well operationally as the parts. The Soviets have clearly experienced gaps between plans and performance in space and weapon systems, and even catastrophic shortcomings. Without tests, the Soviets could not confidently predict how soon a new device could be made to work after "breakout" —if at all. An ASAT test ban could serve U.S. interests by exploiting Soviet uncertainties and fear of detection, while leaving the U.S. free to complicate the Soviet's "breakout" task through a variety of satellite defensive measures.

In sum, there are no obvious reasons why an arms control agreement banning space tests and use of ASAT weapons could not be adequately verifiable. There may be some areas of uncertainty, but not so great as to permit the Soviets to pose a significant, unanticipated threat to U.S. security if we take prudent steps towards improving intelligence capabilities and diversifying and protecting vital satellite functions.

7. COMPARISON WITH THE 1981 SOVIET DRAFT TREATY

There are several important contrasts between the treaty proposed here and the provisions of the Soviet Union's draft treaty placed before the U.N.

The first contrast is in comprehensiveness. Article 1 of the Soviet treaty addresses weapons placed in orbit around the earth. Strictly speaking, the Soviet formulation does not appear to limit further tests and development of either the Soviet or U.S. ASAT systems. In space tests, the current Soviet interceptor goes into orbit before attacking its target, but it may well be able to attack satellites by direct ascent or after partial orbit. The U.S. ASAT is a direct-ascent interceptor that does not go into orbit. Hence, both seem to elude a ban on weapons "placed in orbit." Ground-based laser ASATs also elude the Soviet formulation. In contrast, the treaty proposed here prohibits all testing of ASAT weapons in space or against objects in space, whether the ASAT weapon is ground- or space-based. This includes tests against one's own space objects, not (as the Soviet text reads) just those of other parties.

A second contrast concerns Article I of the Soviet draft treaty, which reads, in part, "the parties undertake not to station such weapons in outer space . . . , including on reusable manned space vehicles." Because the U.S. Space Shuttle is the only such vehicle now in use, such specific mention in the Soviet proposal must raise suspicions that the Soviets intend to somehow impair the Shuttle program. This impression was compounded by the fact that the English text of the treaty used by some nations in the U.N. left out the crucial word "on." The draft was therefore understood to include "reusable manned vehicles" among the weapons banned from space. Specific mention of reusable manned vehicles is in fact superfluous and is dropped from our proposed treaty text. Any general obligation not to test or place anti-satellite weapons in space would apply, no matter what launch vehicle happened to be used. The Soviets would be banned from using their current space vehicles, such as Salyut or Progrez, or any future Soviet shuttle, for such purposes. The same constraints would of course apply to the U.S. Space Shuttle.

A third contrast concerns Article 3 of the Soviet draft treaty, which contains a general ban on the use of weapons in outer space. The Soviet version, however, adds a reservation: the satellites of the other side would enjoy protection if they did not violate other restraints in the treaty. Here, and in Article 2, the Soviet draft seems to attempt a general limitation on satellites, rather than upon anti-satellite weapons. Indeed, the Soviet formulation gives an impression of legitimizing attacks upon satellites engaged in certain acts, rather than forbiding such attacks.

There are two underlying issues here: first, what rights would one side retain if the other tested or used an anti-satellite weapon in violation of the treaty; and

second, what would the sides be permitted if a third nation tested or used an ASAT weapon in space? On the first point, obviously any violation of ASAT limits by the U.S. or the Soviet Union would be a grave act, and the other side would be justified in exercising rights of withdrawal from the treaty. Such provisions for withdrawal, customary in previous arms control treaties, are adequate to cope with this issue when buttressed by prudent satellite survivability measures.

The second point underscores the importance of eventually transforming a bilateral ASAT treaty into a multilateral accord. It would be regrettable indeed if some third nation undercut superpower limitations upon space arms competition by launching its own ASAT. Still, a bilateral ASAT treaty between the superpowers should not contain provisions that appear to sanction attacks upon the space objects of third nations. If third parties disrupt the agreement reached by the superpowers, the first recourse for the U.S. and Soviet Union should be consultation, as is provided for in the attached treaty. The final recourse would be inherent right of withdrawal where extraordinary events jeopardize supreme national interests.

Finally, the introduction of the Soviet draft proposal in the U.N. General Assembly raises the question of whether the best prospect for space arms control is through multilateral or bilateral negotiations. A superpower arms competition in space would certainly be a matter of global concern. Objects circling the earth in outer space can come within a hundred miles or so of every point on the globe, of every nation on earth. Outer space can be used in a host of ways to yield security and prosperity for all nations. It is therefore desirable that any arms control restraints on weapons in outer space be broadly affirmed and respected by all nations.

At the moment, however, only the Soviet Union and the U.S. have ASAT programs. Since their accession is indispensable to any meaningful limitations on space weapons, and since their ASAT programs are proceeding apace, it is most important that the superpowers begin direct negotiations, unimpeded by the delays that unavoidably arise in wider multilateral forums.

The best course, therefore, would be for the U.S. and the Soviet Union to begin direct negotiations on bilateral restraints, keeping in mind the desirability of eventually incorporating their accord into a multilateral treaty appropriate for signature by all nations.

NOTES

1. Presidential Directive 37. Summarized in public document released by the White House, June 19, 1978.

2. U.S., Congress, Senate, Committee on Foreign Relations, Subcommittee on Arms Control, **Arms Control and the Militarization of Space: Hearings on Arms Control**, 97th Cong., 2d sess., 20 September, 1982; testimony by Robert W. Buchheim.

3. **Ibid.**, testimony by Eugene Rostow.

4. **Ibid.**, testimony by Richard D. DeLauer.

   U.S., Congress, House, Committee on Armed Services, Subcommittee on Research and Development, **Hearings on Arms Control**, 17 March 1983; testimony by Robert S. Cooper.

   Smith, Marcia. "Antisatellites," Congressional Research Service, Library of Congress. Issue Brief No. IB81123, April 6, 1983.

5. U.S., Congress, Senate, **S.R. 43**, 2 February 1983.

   U.S., Congress, House, **H.R., 120**, 2 February 1983.

   U.S., Congress, Senate, **S.R. 28**, 2 February 1983.

6. Meyer, Stephen M. **Soviet Military Programs and the "New High Ground"**. Cambridge, Mass.: Center for International Studies, Massachusetts Institue of Technology. To be published in **Survival**.

7. Johnson, Nicholas L. **The Soviet Year in Space: 1982**. Colorado Springs: Teledyne Brown Engineering, January 1983.

8. U.S., Congress, Senate, Committee on Commerce, Science, and Transportation, **Soviet Space Programs: 1976-80**, 97th Cong., 2d sess., December 1982; Committee Print prepared at the request of the Honorable Bob Packwood, Chairman.

9. Jasani, B., ed. **Outer Space — A New Dimension of the Arms Race**. London: Stockholm International Peace Research Institute, Taylor & Francis, 1982.

10. DMS Inc., Missiles/Spacecraft. **Market Intelligence Reports**. Greenwich, Connecticut, 1982.

11. Johnson, Nicholas L. "Estimated Operational Lifetimes of Several Soviet Satellite Classes," **Journal of British Interplanetary Society**, 34:280-283, 1983.

12. U.S., Congress, House of Representatives, Report prepared by the Congressional Research Service for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, **United States Civilian Space Programs: 1958-1978**, 97th Cong., January 1982.

13. Royal Aircraft Establishment. **The RAE Table of Earth Satellites: 1981-1982**. Farnborough, Hunts, England, January, 1983.

14. Karas, Thomas. **The New High Ground**. New York: Simon and Schuster, 1983.

15. Johnson, Nicholas L. **The Soviet Year in Space: 1981**. Colorado Springs: Teledyne Brown Engineering, January 1982.

16. U.S. Department of Defense. **Soviet Military Power - 1983**. March 1983.

17. The term "space objects" would correspond to "objects launched into outer space" in the Outer Space Treaty of 1967. Such objects include not only all functioning objects commonly called "satellites," but also all objects on interplanetary flights as well as all man-made pieces of debris. The term does **not** include nuclear missile warheads on ballistic trajectories, even though these pass through space. Hence, an ASAT treaty along these lines would not alter the rights or obligations of the 1972 ABM Treaty which covers weapons used against ballistic missiles.

18. U.S., Congress, House Committee on Foreign Affairs and Senate Foreign Relations Committee. **Fiscal Year 1984 Arms Control Impact Statements**, 98th Cong., 1st sess.; Submitted to the Congress by the President Pursuant to Section 36 of the Arms Control and Disarmament Act, April 1983; see especially pp. 131-134 and 265-267.

19. Smith, R. Jeffrey, "The Search for a Nuclear Sanctuary," **Science**. 221:30, July 1, 1983.

Appendix I

A TREATY LIMITING ANTI-SATELLITE WEAPONS

Preamble

ARTICLE I

Each Party undertakes not to destroy, damage, render inoperable or change the flight trajectory of space objects of other States.

ARTICLE II

1. Each Party undertakes not to place in orbit around the earth weapons for destroying, damaging, rendering inoperable, or changing the flight trajectory of space objects, or for damaging objects in the atmosphere or on the ground.

2. Each Party undertakes not to install such weapons on celestial bodies, or station such weapons in outer space in any other manner.

3. Each Party undertakes not to test such weapons in space or against space objects.

ARTICLE III

1. For the purpose of providing assurance of compliance with the provisions of this treaty, each Party shall use national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.

2. Verification by national technical means shall be supplemented, as appropriate, by such cooperative measures for contributing to the effectiveness of verification by national technical means as the Parties shall agree upon in the Standing Consultative Commission.

3. Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this Article.

4. Each Party undertakes not to use deliberate concealment measures which impede verification by national technical means of compliance with this treaty.

ARTICLE VII

Each party undertakes not to assume any international obligation which would conflict with this treaty.

ARTICLE VIII

1. Each Party may propose amendments to this treaty.

2. Agreed amendments shall enter into force in accordance with the procedures governing the entry into force of this treaty.

ARTICLE IX

This treaty shall be of unlimited duration.

ARTICLE X

Each Party shall, in exercising its national sovereignty, have the right to withdraw from this treaty if it decides that extraordinary events related to the subject matter of this treaty have jeopardized its supreme interests. It shall give notice of its decisions to the other Party six months prior to withdrawal from the treaty. Such notice shall include a statement of the extraordinary events the notifying Party regards as having jeopardized its supreme interests.

ARTICLE XI

1. This treaty shall be subject to ratification in accordance with the constitutional procedures of each Party.

2. This treaty shall enter into force on the day of the exchange of instruments of ratification.

ARTICLE XII

1. Done in two copies, each in the English and Russian languages, both texts being equally authentic.

2. This treaty shall be registered pursuant to Article 102 of the Charter of the United Nations.

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ARTICLE IV

1. To promote the objectives and implementation of the provisions of this treaty, the Parties shall use the Standing Consultative Commission, established by the Memorandum of Understanding Between the Government of the United States of America and the Government of the Union of Soviet Socialist Republics regarding the Establishment of a Standing Consultative Commission of December 21, 1972.

2. Within the framework of the Standing Consultative Commission, with respect to this treaty, the Parties will:

a) consider questions concerning compliance with the obligations assumed and related situations which may be considered ambiguous;

b) provide on a voluntary basis such information as either Party considers necessary to assure confidence in compliance with the obligations assumed;

c) consider questions involving unintended interference with national technical means of verification, and questions involving unintended impeding of verification by national technical means of compliance with the provisions of this treaty;

d) consider, as appropriate, cooperative measures contributing to the effectiveness of verification by national technical means;

e) consider possible changes in the strategic situation which have a bearing on the provisions of this treaty, including the activities of other States;

f) consider, as appropriate, possible proposals for further increasing the viability of this treaty, including proposals for amendments in accordance with the provisions of this treaty.

ARTICLE V

The Parties undertake to begin, promptly after the entry into force of this treaty, active negotiations with the objective of achieving, as soon as possible, agreement on further measures for the limitation and reduction of weapons subject to limitation in Article II of this treaty.

ARTICLE VI

In order to ensure the viability and effectiveness of this treaty, each Party undertakes not to circumvent the provisions of this treaty, through any other State or States, in any other manner.

Appendix II

ANSWERS TO WRITTEN QUESTIONS POSED BY SENATE FOREIGN RELATIONS COMMITTEE TO RICHARD GARWIN, NOEL GAYLER, AND KURT GOTTFRIED ON May 18, 1983

June 3, 1983

QUESTION 1: What do you regard as the most destabilizing developments in current and future space programs?

Response: In our view the most destabilizing aspects of current and future US and Soviet space programs are:

a) The continuing testing of the Soviet ASAT;
b) the upcoming tests of the US F-15 ASAT;
c) the absence of any negotiations to limit the further growth of ASAT capabilities; and
d) President Reagan's speech of March 23, 1983, setting a US course towards a perfect defense against all nuclear-armed missiles (as interpreted on national television by Secretary of Defense Weinberger on March 27, 1983).

Taken together, these actions and policies are:

i) planting the seeds for a capacity that will, if allowed to grow, threaten our space-borne warning systems with preemptive attack; and

ii) seriously imperil the ABM treaty, and with it our confidence that our retaliatory forces continue to retain the ability to penetrate Soviet defenses.

Even though there is no scientific justification for holding out hope for a leak-proof space-based defense against nuclear weapons, the quest for such a defense will, even if futile, have destabilizing consequences. In particular, the prospect of a space-based BMD system is certain to spawn the development of space mines by the adversary, which will hound the BMD platforms to assure penetration of ICBMs. Space mines will be developed even if, as is most probable, no BMD capability is ever achieved, and these mines will then threaten all objects in space, whether they carry weapons or not. This could lead to war in space as a prelude to war on earth.

QUESTION 2: In his March 23 speech, President Reagan stated that if laser defense was "paired with offensive systems, they can be viewed as fostering an aggressive policy."

a) Do you agree with this assessment?
b) If so why? If not, why not?
c) Some have argued that if we can reduce offensive weapons to the point that they no longer appear offensive then there would be no need for a space-based BMD system. Do you agree?

Response:

a) We agree that an effective defense against nuclear weapons, when paired

with the existence of offensive systems, would "support an aggressive policy." But as we make clear in our responses to Questions 9 & 10, we do not accept the underlying assumption in the President's statement, to wit, that an effective defense against missile-borne nuclear warheads can be built.

b) It can support a coercive policy. In fact, held by one side, such capabilities would allow world domination. Paradoxically, if offensive and perfect defensive weapons were available to both sides (leaving aside the rest of the world for the moment), there would be no feeling of serenity, since it would be quite obvious that the effectiveness of a defense might be destroyed catastrophically by sabotage, deception, or the like.

c) We doubt that either the Soviet Union or the United States is likely to give up offensive weapons and the insurance of deterrence by threat of retaliation. Yes, we suspect that it would be easier to negotiate away offensive weapons than to build an effective space-based BMD system.

QUESTION 3: Some government officials contend that any Soviet missile can serve as an ASAT launcher. Accordingly, it is argued, verification of an ASAT ban could be difficult, if not impossible. Do you agree with this view?

Response: In all 20 reported tests of their ASAT interceptor over the past 15 years, the Soviets have used only one launch booster, a missile based on the old SS-9 "heavy" ICBM. Therefore, the Soviets lack ASAT experience with any other missile. Anyone who imagines that "any Soviet missile can serve as an ASAT launcher" displays a lack of awareness of the difficulties that habitually plague space hardware programs, and the Soviet ASAT program in particular. If the Soviets sought to use a different booster, they would confront several obstacles. First, if the interceptor itself has been specially designed to fit onto the SS-9 missile, it would have to be redesigned to fit a new booster, and the new configuration would require space tests to confirm that the entire system worked properly in its new form. Such tests would be visible to U.S. surveillance systems. Secondly, the bulk of Soviet space launch boosters and operational ICBMs have launch- and payload-weights no greater than the SS-9, and the Soviets would gain little by putting their ASAT on a different missile that was only comparable or inferior to the current booster. Thirdly, the SS-9 itself has been phased out and replaced by the SS-18. If the Soviets sought to put their ASAT interceptor on a silo-based SS-18, then the silo too must be designed to accommodate the extra length and special launch-preparation requirements of the interceptor. Major modifications to operational silos, if they were required, would be monitored by U.S. intelligence systems, as could space test of the new SS-18/ASAT configuration.

Finally, there are Soviet boosters that are larger than the SS-9, such as those used for the Soyuz and Salyut programs, and these in principle could carry the Soviet ASAT to higher altitudes. However, attacking satellites at higher altitudes places greater demands upon an interceptor, e.g., greater homing range, greater guidance accuracy, greater maneuvering power. Such improvements in an interceptor would also require space tests to confirm. So, even if the Soviet interceptor could be mounted on a different booster, that alone could not increase the threat it

poses, as long as further space tests are banned.

A prompt ban on further ASAT space tests would serve U.S. interests by inhibiting any such improvements to the current Soviet ASAT system.

QUESTION 4: The Soviets have tabled a draft treaty that would ban all weapons from space. This treaty would apparently allow the Soviet Union to retain its current ASAT. How does your proposal differ with the Soviet proposal? Do you see the Soviet draft treaty as a realistic basis for negotiations?

Response: The Soviet Draft Treaty placed before the U.N. in 1981 suggests a serious interest in reaching an arms control agreement in space weaponry. The Soviet draft contains some elements that are worthy of serious consideration, even though the treaty draft is not acceptable as it stands. The degree to which it is unacceptable can be gauged from the remainder of this response.

The most important differences between the Soviet draft and the one put forward by us are that our draft forbids:

a) Tests against space objects in one's possession;

b) Tests from weapons on the ground;

c) Tests against objects on the ground or in the atmosphere from weapons in space.

Furthermore, our draft does not permit attacks against space objects that are in violation of the treaty's provisions; it addresses this problem in the traditional manner, by providing for withdrawal from the obligations of the treaty after due notice. Finally, our draft is bilateral.

QUESTION 5: Your proposal bans ASAT testing but not ground-based ASAT deployments. Given the fact that the Soviets have tested their ASAT, would your proposal be in effect a one-sided ban directed against the United States? If your proposal were in force, what incentives would the Soviet Union have for agreeing to dismantle their ASAT?

Response: Our discussion shows that our proposed treaty would not be to the "one-sided" disadvantage of the United States. If our treaty were to come into force, the USSR will have a tested ASAT, but one which has shown itself to be very unreliable, while the US would have under advanced development a more flexible and potent ASAT that had not yet been tested. Under the treaty regime we propose, the US would probably be closer to a prompt, flexible, all-altitude ASAT system than the USSR, while neither existing capability would pose much of a threat to those satellites on either side that are vital if nuclear war should break out.

In striking a balance of advantage versus disadvantage, one must consider factors other than the capabilities of the two ASAT systems. Since the United States is, on balance, more dependent on satellites for its security, anything that inhibits the evolution of the Soviet ASAT threat could be viewed as a "one-sided" advantage for the US.

The main incentive the Soviets would have for agreeing to dismantle their ASAT, would be their awareness that their current ASAT system would become progressively obsolete anyway. In the absence of space tests, the Soviets would

be left with an unreliable interceptor based upon 1960s technology, while the U.S. remained free to adopt sophisticated measures for protecting and diversifying its satellite functions.

QUESTION 6: Even if the Soviet ASAT capability is viewed as limited, does it not amount to a significant threat, given the high level of U.S. dependence upon a relatively small number of satellites?

Response: The Soviet ASAT, as presently constituted, could, over a period of several days, destroy a significant portion of our space-based capability for photo reconnaissance, which is of greatest importance in peacetime. It has quite limited capability against the remainder of our space-based command, control, communications, and intelligence systems; in particular, it has virtually no capability against that portion of the system that would be employed by the strategic forces in wartime. Nevertheless, the US should consider the desirability of various measures for protecting its satellites, or, for example, of providing ground-based back-up C systems for satellites important to theater conflicts.

QUESTION 7: We have previously used national technical means of verification to observe the dismantling of launchers.

a) Did you consider an ASAT ban involving the dismantling of Soviet ASAT launchers?

b) If yes, why did you not adopt this as your proposal?

Response: a) We have considered an ASAT ban involving the dismantling of Soviet ASAT launchers.

b) We did not adopt this as our proposal because we see no way in which the Soviets could verify that the United States had destroyed its F-15 ASAT system, and the difficulty of negotiating a non-symmetric treaty far exceeds the additional benefit we would obtain by destruction of the existing Soviet ASAT. Furthermore, dismantling of the known Soviet launch sites would not guarantee that the Soviet Union did not retain some ASAT capability.

Our draft treaty does include a provision (Article V) requiring the sides to begin negotiations on this issue immediately after a ban on space tests of ASATs is reached. However, we also recognized that provisions for dismantling ASAT systems could be quite complicated, and would, at best, require long negotiations. Hence, we view our proposed ban on further ASAT space tests as an urgent and indispensable first step toward any wider ASAT arms control measures. (For other closely related remarks, see our response to Question 12).

QUESTION 8: Senator Matsunaga and I [Senator Pell] are cosponsoring a concurrent resolution, S. Con. Res. 16, expressing the sense of the Congress that the President should initiate talks with the Soviet Union and other governments to explore opportunities for cooperative East-West ventures in space, as an alternative to an arms race. Do you support such a resolution?

Response: We support the Resolution sponsored by Senators Matsunaga and Pell. We agree that cooperation in space would be an important ingredient in creating an atmosphere that would inhibit confrontation. But we do not think that

such cooperation, by itself, would preclude an arms race in space. Cooperation should be viewed as one component in a diplomacy that seeks to avert such a race; the other, indispensable component, is a treaty that restricts the evolution of space-based weapons.

QUESTION 9: Do you believe that a space-based ABM system of even limited capacity could ever be built?

Response: A spaced-based ABM system of **very** limited capacity could be built **provided** the enemy abstained from taking rather simple and relatively cheap countermeasures.

QUESTION 10: Do you believe that such a system could ever effectively protect the United States from nuclear attacks?

Response: We are persuaded that such a system could never effectively protect the United States from an intentional large-scale missile attack from the Soviet Union, and even less could it protect against the systems the Soviets would develop in order to penetrate, circumvent, and destroy such a defensive system.

QUESTION 11: If we do not institute effective controls on weapons in space, what do you think will be the result?

Response: Without an effective ban on weapons in space, and a ban on antisatellite tests and activities, we are persuaded that the striving for ASAT and ABM capabilities could lead to war in space during what would otherwise have been peacetime, which would almost certainly lead to war on earth. This is so because it is very much simpler to achieve an ASAT capability than an ABM capability. Satellites are intrinsically more vulnerable than ballistic missiles; furthermore, the nature of the satellite's trajectory allows ample time for target acquisition, and for repeated attacks. Any space-based BMD capability, therefore, has an inherent ASAT capability, even if its potency against ICBMs is actually minimal. In particular, such a nascent ABM system can preemptively destroy an imagined ABM system belonging to the other side. Furthermore, either side can, at an early stage, station space mines that have the capacity for preemptive destruction of any satellites carrying ABM systems deployed by the other.

QUESTION 12: Why doesn't your draft treaty ban land-based ASATs? Would you favor such a ban if effective verification could be worked out?

Response: Our treaty bans all **tests** of land-based ASATs in space or against objects in space. Effective verification of a provision that also bans **possession** of land-based ASATs would require very intrusive verification measures, including extensive on-site inspection. For example, the U.S. ASAT interceptor and its launch booster are fairly small and could readily be hidden in many places at U.S. military facilities. Even the U.S. might find such intrusive on-site inspection at military bases unacceptable. As for the Soviet ASAT, even though it is large it could be launched some of the boosters used in the Soviet space program (see response to Question 3, however). Therefore dismantling of the launchers that have been used for Soviet ASAT test shots would not, by itself, guarantee that

there was no remnant Soviet ASAT capability.

One must bear in mind that the existing Soviet ASAT is intrinsically of rather limited capability. The prevention of any significant enhancement of that capability should therefore be the **primary** objective of U.S. policy, not the elimination of a relatively minor threat.

We recognize that a comprehensive ban on ASAT possession would be desirable, and for that reason our draft treaty, through Article V, obligates the parties to promptly begin negotiations towards that end as soon as the ASAT test ban is in place. If a treaty that would adequately verify lack of possession could be formulated, we certainly would support it. But given the limited political capital and human resources available for any negotiation, and the urgent need for a viable restriction on the growth of ASAT capabilities, we do not favor a negotiation position that may sacrifice the attainment of an ASAT test ban to the search for a ban on possession.

Appendix III

TABLE 1
UNITED STATES MILITARY SATELLITE SYSTEMS

MISSION	CLASS	INITIATED	'82 LAUNCHES	COMPLEMENT	INCLINATION	PERIOD	PERIGEE	APOGEE	LIFESPAN
Communication	DSCS II	1971	1	4 + 2	2.0	G	G	G	5 years
	DSCS III	1982	1	*	2.5	G	G	G	10 years
	SDS	1971	0	2	63.5	700	250	39,300	2 years
	FLTSATCOM	1978	0	4 + 1	2.0	G	G	G	5 years
	NATO	1970	0	3	2.8	G	G	G	7 years
	MARISAT	1976	0	3	2.5	G	G	G	10 years
	LES	1965	0	♦♦	25.0	G	G	G	♦♦
	AFSATCOM***								
Navigation	Transit	1964	0	5	90.0	105	1,075	1,100	♦♦
	NOVA	1981	0	**	90.0	110	1,170	1,190	6 years
	NTS	1974	0	(1)	125.1	468	13,440	13,770	♦♦
	NAVSTAR	1978	0	6 @	63.0	720	20,200	20,300	5-7 years
Meteorology	NOAA	1970	0	2	99.0	102	810	860	18 months
	DMSP	1971	1	2	99.0	102	810	870	3 years
Early Warning	DSP	1970	1	3	2.0	G	G	G	2-5 years
Nuclear Explosion Detection°	Vela Hotel	1963	0	2	32.5	6730	110,900	112,200	10+ years
Electronics Intelligence	Rhyolite	1973	0	4	0.2	G	G	G	3-6 years
Ocean Reconnaissance	NOSS	1976	0	6	63.4	107	1040	1170	♦♦
Photographic Intelligence	Key-Hole (KH-9)	♦♦	0	(1)	96.5	♦♦	52	119	6 weeks
	Big Bird	1971	1	(1)	96.0	89	150	330	3-5 months
	KH-11	1976	2	2	97.0	93	220	550	2+ years
Geodesy	GEOS-3	1975	0	♦♦	115.0	102	840	855	♦♦
	LAGEOS	1976	0	♦♦	110.0	225	5840	5950	♦♦

G = Geosynchronous orbit: Satellite moves with same period as the Earth at an altitude of approximately 35,600 km.
♦♦ = Statistic uncertain or unavailable using unclassified literature.
* = DSCS III is follow-on to DSCS II; same complement is planned.
** = NOVA satellites are being incorporated into the Transit network.
*** = AFSATCOM equipment is housed on "host" SDS, FLTSATCOM, LES, and DSCS III satellites.
@ = NAVSTAR plans call for a network of 18 operational satellites and three spares by 1988.
Apogee = Highest known point of orbit above the earth, given in km.
° = Other nuclear explosion detection sensors are aboard DSP and SDS satellites. The NAVSTAR system will house an advanced nuclear explosion detection system called IONDS beginning with NAVSTAR-8. Soviet nuclear detection sensors are most likely on their early warning and/or Molniya communication satellites.
Complement = Indicates the nominal number of satellites in a given network; + designates spares in orbit; ( ) = uncertain complement.
Inclination = Highest latitude reached N and S, given in degrees.
Period = Time it takes to complete one orbit, given in minutes.
Perigee = Lowest altitude of same orbit as apogee, also given in km.

TABLE 2
SOVIET MILITARY SATELLITE SYSTEMS

MISSION	CLASS	INITIATED	'82 LAUNCHES	COMPLEMENT	INCLINATION	PERIOD	PERIGEE	APOGEE	LIFESPAN
Communication	Com 1	1970	4	3	74.1	101	790	810	17 months
	Com 2	1970	2 @	24	74.0	115	1385	1565	5 months
	Molniya 1	1965	4	8	62.9	718	400	39,900	2 years
	Molniya 3	1974	2	4	62.9	718	400	39,900	2 years
	Raduga	1975	1	2 + 2	0.3	G	G	G	**
	Gorizont	1978	2	**	0.8	G	G	G	**
Navigation	Nav 2	1974	6	6	82.9	105	965	1020	16 months
	Nav 3	1976	2	4	82.9	105	965	1020	3 years
	GLONASS*	1982	3	3	64.8	673	19,075	19,075	**
Meteorology	METEOR 1	1969	0	(1)	98.0	98	630	680	**
	METEOR 2	1975	2	(3)	82.5	104	870	940	**
Early Warning	EW-1	1972	5	9	62.8	718	400	40,000	20 months
Electronics Intelligence	ELINT 2	1970	4	6	81.2	97	620	640	20 months
Ocean Reconnaissance	EORSAT	1979	5	(2)	65.0	93	425	445	6 months
	RORSAT	1967	4	(2)	65.0	90	250	265	3-4 months
Photographic Intelligence	Low Resolution	1962	3	(1)	82.3	89	210	250	2 weeks
	Med Resolution	1968	8	(1)	70.3	92	350	450	2 weeks
	HI Resolution-1	1963	23	(1)	65-80	89	170	360	2 weeks
	HI Resolution-2	1975	1	(1)	65-70	89	170	370	6 weeks
Geodesy	Geod-1	1968	0	**	3.0	109	1140	1430	**

G, ** - See footnotes beneath Table 1.

* = GLONASS will be a navigation network similar to the U.S. NAVSTAR system; 9-12 operational satellites are expected.

@ = Com 2 satellites are launched in octets by a single carrier rocket.

Electronics Intelligence (ELINT) satellites detect and intercept foreign communications and radar signals.

Geodetic satellites gather precise information about the earth's gravitational and magnetic fields; this information is used to improve missile guidance.

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SPACE WEAPONS, THE KEY TO ASSURED SURVIVAL

INTRODUCTION

As a result of congressional efforts to ban U.S. testing of weapons in space[1] and the recent testing of an anti-satellite (ASAT) weapon by the United States, increased attention is being directed to the question of whether the United States should have a space weapons[2] capability. Given the Soviet space weapons and treaty compliance record, along with the benefits to U.S. military security, the continued development of space weapons is in the U.S. national interest. Perhaps more important, a ban on space weapons would prevent the U.S. from deploying defensive space weapons as part of the strategic defense system envisioned by President Reagan. Such a strategic defense system would help protect the U.S. homeland from nuclear attack, reinforce deterrence, protect U.S. conventional forces and satellites from Soviet threats, and help stabilize crisis situations.

The control of space weapons through a negotiated agreement with the Soviets is a flawed idea. First and foremost, an ASAT ban would deny the U.S. the opportunity to develop and deploy the most essential feature of a strategic defense system--a ballistic missile defense (BMD) system. A BMD system would inevitably have ASAT capabilities and would be banned also. The U.S. thus would be locked into reliance on offensive nuclear forces to deter attack, and the threat of almost total societal destruction in a nuclear conflict would remain.

Second, an ASAT ban would not even accomplish what its proponents claim it would, that is, the protection of U.S. space assets. Such a ban would be virtually impossible to verify, and the Soviets' compliance with past arms control agreements is poor enough to suggest that, given the opportunity, they would find ways to circumvent an ASAT ban.

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There are, of course, many technological barriers left to cross before the U.S. achieves an effective strategic defense. But the potential benefits of space weapons are far too great--and the present dangers far too real--to bargain away a chance for real security.

BACKGROUND

Soviet long-range, nuclear-tipped ballistic missiles could destroy the U.S. as a viable society in hours, if not minutes. Early in the missile age U.S. scientists recognized the potential of space weapons to shoot down Soviet missiles as they travelled through space in high arcs to targets in the United States. The Eisenhower Administration in 1959 initiated a crash research and development effort, called Project Defender, to develop a multi-tiered ballistic missile defense force with space weapons in the first layer.[3] Although early studies were optimistic about technical feasibility, Project Defender was cancelled in part because the Soviet ICBM threat did not materialize as soon as expected and because the Kennedy Administration wanted to build up U.S. strategic offensive and conventional forces for deterrence.

Since the mid-1960s, the U.S. has based its security against nuclear attack solely on deterrence through retaliation. U.S. thinking about strategic nuclear affairs has been dominated by the view that defending populations against missile attack is not cost-effective. Many opponents of strategic defense also have subscribed to the doctrine of "mutual assured destruction" (MAD), which holds that to deter nuclear war the U.S. and the Soviet Union must have the capability to inflict "assured destruction" (massive civilian casualties and economic devastation) on each other. According to MAD, defending populations is bad, because it would upset the "balance of terror" and be perceived as a threatening bid for nuclear superiority by the other side. The result: a futile arms race and increased tensions between the superpowers. Under the sway of MAD, the U.S. government abandoned plans for a nationwide anti-ballistic missile (ABM) system in the mid-1960s, virtually dismantled U.S. civil and air defenses, and in 1972 signed a treaty with the Soviet Union limiting deployment of ABM systems to two sites (later reduced to one), thereby foreclosing the option of population defense.

Changes in the decade and a half since anti-missile defenses were rejected, however, are sufficient to warrant a reappraisal of strategic defense. Science has made tremendous breakthroughs on many fronts. A 1983 study by a group of top scientific experts (the Defense Technologies Study Team) concluded that technological advances of the last 25 years and those anticipated in the next 10 years make space-based ballistic missile defense feasible even against sophisticated Soviet countermeasures.[4] Advances in ground-based missile defense technology and anti-bomber/anti-cruise missile technology also have been considerable.

The strategic need for population defenses is far greater today than in the mid-1960s. The Soviet Union has never accepted U.S. views of deterrence, which stress the need for mutually secure second-strike forces. In accordance with its explicit nuclear war-winning strategic doctrine,[5] the Soviet Union has deployed a large force of very powerful land- and sea-based ballistic missiles. Using less than one-half of its total force, the USSR could destroy in a first strike up to 90 percent of America's silo-based ICBMs, 70 percent of the U.S. strategic bomber force, 40 percent of U.S. missile firing submarines, and key components of the U.S. command and control structure essential for effective retaliation.[6]

Soviet Strategic Defense

The Soviets also have invested heavily in strategic defenses to protect vital Soviet military, economic, and political assets from whatever retaliation the U.S. could muster after a Soviet first strike. Soviet air defenses, for example, comprise 2,500 interceptor aircraft, 10,000 surface-to-air missiles (SAMs), and 5,000 radars--which are being upgraded with new interceptors with look-down/shoot-down radars and missiles, new SAMs, and airborne warning and control aircraft (AWACs) to defend against low flying U.S. bombers and cruise missiles.[7] The Soviets spend about $3 billion a year on civil defense programs, which are capable of reducing Soviet civilian casualties to World War II levels under certain conditions.[8] (Congress appropriated $169 million for U.S. civil defense in FY 1984.)

The Soviet Union signed the 1972 ABM treaty not because Soviet leaders agreed that populations should remain defenseless but, more likely, because they wanted to prevent the U.S. from protecting its ICBMs and other strategic assets from a Soviet attack.[9] Since 1972, the Soviet Union has energetically pursued ABM research and development--the U.S. dismantled its one ABM site in 1976--and is currently upgrading its ABM system around Moscow with new radars and interceptors.[10] Some of the upgrades violate the 1972 ABM Treaty. Reportedly, the Soviet Union has built facilities for mass production of ABM system components that would give the USSR the capability for rapid deployment of a nationwide ABM system.[11]

The Soviet Union is also developing ground- and space-based directed energy weapons (lasers and particle beams)[12] for destroying U.S. ballistic missile warheads. According to the Defense Department, the USSR is spending three to five times more than the U.S. on research and development of laser weapons and could deploy the world's first orbiting laser weapon satellite in the next five years,[13] thus providing valuable operational experience for a multi-platform space missile defense system that could be deployed around the turn of the century.[14] The Soviets are already conducting tests of pointing and tracking mechanisms for laser weapons[15] (similar U.S. experiments are not scheduled until 1987) and apparently have test fired an experimental ground laser weapon located at Sary Shagan against Soviet reentry vehicles.[16]

Thus, it is clear that the unrelenting offensive buildup by the Soviets jeopardizes the survival of American nuclear deterrent forces. The Soviets' defensive measures have further degraded the effectiveness of the U.S. deterrent and their continued research, development, and production confront the U.S. with the disconcerting possibility of a rapid expansion of Soviet defensive capabilities and a potentially decisive Soviet strategic superiority.

BENEFITS OF U.S. SPACE WEAPONS

Why Strategic Defense?

To offset Soviet advantages in the strategic nuclear balance, the U.S. must enhance the survivability of its offensive nuclear forces and improve their capability to threaten important Soviet military targets. To maintain U.S. security in the long run, however, requires a fundamental change in the U.S. force posture: deployment of defense systems to protect the U.S. homeland from nuclear attack.

There are at least four strong arguments for the development of a strategic defense capability:[17]

1) Strategic defense would bolster deterrence by denying the Soviets the ability to destroy U.S. retaliatory nuclear forces and other U.S. economic and military assets. With less certainty of success, the Soviets would be less inclined to attack, even in crisis situations.

2) Strategic defense would more effectively deter the Soviets from limited nuclear aggression against U.S. allies. By defending the U.S., the credibility of an extended U.S. nuclear umbrella could be improved. The confidence of U.S. allies in U.S. ability and will to assist in their defense would also be restored.

3) Strategic defense would limit the danger of accidental nuclear war. Additional reaction time for leaders would be provided. Accidental launches, rather than detonating on U.S. soil, would be destroyed, thus lessening the chances of escalation.

4) Strategic defense is specifically intended to save lives and limit damage. Given the potentially catastrophic consequences should deterrence fail, such an approach is eminently practical and profoundly more moral than current strategic doctrine which relies heavily on mutual assured destruction.

Space weapons would play a critical role in a strategy of U.S. homeland defense, the key to which is to deploy multiple layers of defense. As Soviet missiles passed through each defense layer, fewer and fewer would survive, thus making the task of defense easier and more effective for each successive layer. It is important to attack Soviet missiles as soon as possible to allow

for multiple defense engagements and to destroy missiles before they disperse their multiple warheads. An effective strategic defense force posture, then, should include space-based anti-ballistic missile weapons capable of destroying Soviet missiles in their vulnerable boost phase (the first few minutes of flight) and space- or ground-based weapons capable of destroying missiles during their gliding stage in space.

The Soviet ASAT Threat

In addition to their contribution to strategic defense, space weapons could help protect U.S. satellites from a growing Soviet ASAT threat. The U.S. depends heavily on satellites for a number of military functions--communications (over 70 percent of U.S. overseas military communication travels by satellite), surveillance, reconnaissance, navigation, and meteorology. This dependency is increasing. Of particular importance to U.S. security are those satellites supporting the U.S. nuclear deterrent forces by providing command, control, and communications channels, early warning of Soviet missile launches, tracking of missile flight paths, damage assessment, and post-attack reconnaissance. These functions are critical for planning and executing controlled retaliatory nuclear strikes against strategically vital Soviet targets (such as nuclear missile silos, command bunkers, and centers of political control). As the Scowcroft Commission and nuclear strategists in both Democratic and Republican administrations have recognized, the capability to reply in kind in a controlled war to the full spectrum of possible Soviet nuclear attacks is essential for stable deterrence.[18]

Destruction of U.S. command, control, and intelligence satellites in a surprise first strike to paralyze U.S. strategic nuclear retaliatory forces seems to be a high priority in Soviet war plans.[19] A large-scale 1982 Soviet nuclear war exercise,[20] for example, commenced with a simulated attack on a U.S. strategic satellite by a Soviet ASAT system--the only ASAT system currently operational.[21] This system consists of a "killer satellite" launched from a variant of the SS-9 Scarp ICBM into a co-planar, intersecting or near orbit to the target.[22]

Two versions of the Soviet ASAT system have been tested: a radar guided satellite that explodes on command near the target; and an infrared guided system that fires pellets at the target. The capability of the Soviet orbiting ASAT system is limited but not insignificant. Although the infrared system has not yet been tested successfully, the success rate of the radar system is 70 percent. Only a few launch pads are dedicated to the ASAT mission, and the Soviet ASAT system is effective only against U.S. satellites orbiting below 900 miles, primarily reconnaissance satellites. On the other hand, the Soviets are modifying their huge SL-12 booster to launch "killer satellites" against U.S. early warning and communications satellites in high orbit,[23] and they may be able to modify their ASAT weapon to perform multiple kills and to function as a space mine.

The USSR is also developing and testing ground- and space-based directed energy and conventional weapons for attacking U.S. satellites in all orbits. Launch of a Soviet prototype orbiting laser ASAT weapon is expected within the next five years, with perhaps six orbiting laser ASAT platforms deployed by 1990.[24] In April 1981, the Soviets launched a large 15-ton maneuvering spacecraft, Cosmos 1267, which reportedly "carried ejection ports for small infrared homing torpedoes capable of destroying military satellites on impact."[25]

U.S. Space Weapons and the Defense of U.S. Satellites

Ensuring survivability of U.S. satellites against Soviet ASAT weapons poses a major challenge to U.S. defense planners. Four methods of enhancing the survivability of U.S. satellites have been discussed: (1) a treaty banning the testing and deployment of ASAT weapons; (2) use of passive survival aids; (3) deployment of U.S. ASAT weapons to deter Soviet ASAT attacks; and (4) deployment of a space defense system to defend U.S. satellites.

An ASAT weapons ban is not the solution to the problem. Because ASAT weapons tend to be small, easy to hide, and easy to disguise, verification of such a treaty would be most difficult.[26] And lack of Soviet compliance with existing arms control treaties raises serious doubts about their compliance with an ASAT treaty.

There are a number of "passive" measures by which the U.S. could enhance satellite survivability, some of which the U.S. government is already funding.[27] Using a wide variety of such measures, the U.S. could probably ensure a high degree of survivability for its satellites against current Soviet ASAT capabilities. The effectiveness of passive measures against later generation ASAT weapons, however, is uncertain.[28]

Trying to deter a Soviet attack on U.S. satellites by deploying a U.S. ASAT system to threaten Soviet satellites (survivability through deterrence) is probably not the solution to U.S. satellite vulnerability. The Soviets are less dependent on satellites for military operations than is the U.S. and, hence, might find it militarily worthwhile to sacrifice their satellites for those of the United States.[29]

In the absence of an ASAT ban, the U.S. could use space missile defense weapons to help protect U.S. satellites against Soviet ASAT attacks. U.S. laser missile defense weapons, for example, or even the new unsophisticated U.S. ASAT weapons just tested could be used to shoot down Soviet space mines. A ballistic missile defense would also improve the survivability of the vulnerable ground installations, which control many U.S. satellites.

In the final analysis, if the U.S. cannot ensure an adequate level of survivability for its satellites at an affordable cost, it may have to rely on more survivable atmospheric systems to perform those functions now performed by satellites. As John

Pike, space analyst for the Federation of American Scientists, has pointed out:

> Surrogate satellites offer a very attractive survivability option. Indeed, the most survivable "satellite" may be an airplane. High Altitude Remotely Piloted Vehicles can provide excellent in-theater weather and reconnaissance information, and a network of these drones could provide theater and transoceanic communications links.[30]

In short, even if U.S. satellites cannot be adequately protected by passive and active measures, there remain ways to ensure that U.S. armed forces can still successfully perform their military missions.

Space Weapons and U.S. Nuclear Force Survivability

Under current conditions, even more than satellites, many ground- and air-based elements of the U.S. strategic deterrent force--satellite tracking and control facilities, airborne and underground command posts, ground-based communications receivers and transmitters, radars, strategic bomber bases, and land-based ICBMs--would suffer extensive damage from a Soviet first strike. U.S. nuclear forces probably would be left blind, paralyzed, and seriously weakened, significantly impairing U.S. ability to implement its nuclear strategy of controlled limited nuclear counterstrikes against Soviet strategic forces. To some extent, passive measures could increase the survival chances of the U.S. nuclear force. Examples: ICBMs could be redeployed in a mobile or multiple protective shelter mode; communication systems could be hardened against nuclear effects, made mobile, or supported with redundant systems. Yet passive measures might not offer enough protection.[31] Active defenses, including weapons to intercept Soviet missiles in space, could substantially enhance strategic force survivability against present and future Soviet first-strike threats. At the minimum, space weapons would complicate Soviet planning for a first strike. The Soviets would not be able to foresee which of their missiles would be destroyed and which of their targets would consequently escape destruction. Adding to Soviet uncertainties clearly enhances deterrence.

Space Weapons and Conventional Force Survivability

The Soviets deploy spacecraft that pose serious threats to U.S. military forces. These include:

- radar and electronic ocean reconnaissance satellites (RORSATs and EORSATs), which track U.S. aircraft carrier battle groups and provide targeting data for Soviet air- and sea-launched cruise missiles and Soviet anti-carrier ballistic missiles;[32]

- manned orbiting space stations, which could provide extremely valuable reconnaissance information about U.S. force deployments;[33]

- navigation, communications, and reconnaissance satellites;
- unmanned "space plane" weapons now being developed, which could deliver nuclear weapons against U.S. carrier task forces.[34]

In some limited way, a U.S. ASAT capability might deter Soviet aggression. Despite the fact that the USSR is less dependent on satellites than the U.S. for important military functions, Soviet satellites contribute significantly to their military potential and that dependence is growing. Should conflict occur, there are passive measures, such as electronic jamming, that U.S. conventional forces could use to counter Soviet space systems. Their effectiveness is uncertain, if only because "counter-countermeasures" are closely guarded Soviet military secrets. Given the current asymmetry of this significance, for the U.S. to attack Soviet satellites first during a conflict makes little sense. If, however, the Soviets were to initiate a war in space by attacking U.S. satellites, a U.S. ASAT capability would be useful in defending U.S. forces. While ideally U.S. forces should be able to fulfill their missions facing threats enhanced by Soviet spacecraft, there can be no argument that reduction of the threat would be desirable.

As noted previously, if the Soviet ASAT threat grows, the utility of U.S. ASAT capability also will grow because of its ability to provide active defense for U.S. space assets. This will make U.S. ASAT capabilities even more essential in the future.

U.S. SPACE WEAPONS PROGRAMS

Technological Options

The U.S. at last is developing and testing a variety of space weapons. In response to the Soviet ASAT threat, the Carter Administration in 1977 approved development of a U.S. ASAT weapon and supported research and development of directed energy weapons (DEWs) for possible use in a variety of space missions, including defense of U.S. satellites (DSAT). In March 1983 President Reagan endorsed the development of space weapons for missile defense of the U.S. population.

The Air Force has just begun testing the booster stage of its ASAT weapon.[35] This system consists of an "impact kill" infrared guided miniature homing vehicle (MHV) launched from a two-stage rocket carried to high altitudes by an F-15 supersonic fighter. As currently configured, the MHV can destroy only Soviet satellites orbiting below 250 miles, but it could be effective against high altitude Soviet spacecraft and "killersats" if mounted on an earth launched booster.

Like the Soviet Union, the U.S. is developing directed energy weapons. The laser development effort, managed by the Pentagon's Defense Advanced Research Projects Agency (DARPA), has focused so

far on a 5-megawatt chemical laser suitable for limited ASAT missions. The Administration's Defense Technologies Study Team, however, has recommended parallel development of more powerful laser weapons, including ground-based "excimer" lasers and nuclear powered X-ray systems, for use against Soviet ballistic missiles.[36] A restructuring of the laser program is in progress to reflect the new mission of ballistic missile defense. Other laser technology programs include development of target acquisition, laser pointing, and tracking mechanisms (Project Talon Gold) and development of large mirrors for laser beam focusing and control. The development timetable of laser weapons is contingent on funding levels, but some experts believe that a U.S. prototype orbiting space defense laser weapon could be ready for operational testing in the early 1990s.

Because of their high energy density, neutral particle beam weapons would be more effective than lasers against Soviet ballistic missiles, but their development lags considerably behind that of lasers.[37] As an alternative to directed energy weapons, some scientists have urged the Defense Department to look at conventional off-the-shelf technology for a rapidly deployable space missile defense system. The "High Frontier" study, for example, recommends deployment of a multi-tiered BMD system with the first line of defense held by 432 orbiting platforms each armed with about 45 infrared rockets for intercept of Soviet missiles in their "hot" boost phase.[38] If effective, such a system could be cheaper and quicker to deploy than a laser system.

OTHER ISSUES

Military Effectiveness

Obviously, space weapons will not be cheap. There are no reliable cost estimates yet, but a baseline space defense missile force, capable of destroying a high number of Soviet missiles, could cost from $100-$200 billion. Even if space weapons could be overcome, deployment would still be desirable, if the cost to the Soviets of defeating them were roughly equivalent to, or greater than, the cost of deployment to the U.S. Such a system would presumably offer some benefit by retaining at least a degree of effectiveness and would, at the very least, divert Soviet military resources from more directly threatening programs.

Although space weapons present serious technological challenges, almost all scientists agree that they are technically feasible in the sense that the U.S. (and the Soviet Union) can build beam weapons powerful and accurate enough to destroy ballistic missiles. Critics claim, however, that space weapons have two fatal defects. First, the Soviets can cheaply counter U.S. space weapons by: using ablative coatings or fluids to shield Soviet missiles from lasers; spinning missiles to prevent laser heat buildup; polishing missile skins to reflect laser beams; jamming laser wavelengths; and shielding booster rocket plumes, deploying flares, or modifying boosters for shorter rocket burns to confuse infrared sensors. Second, they claim that U.S. space

weapons would be vulnerable to attack by Soviet space mines, nuclear weapons, amd laser weapons.[39]

These countermeasures pose significant challenges to U.S. space weapons. It is not clear, however, that Soviet countermeasures would be cheap or that the U.S. could not successfully deal with them at an affordable cost. For example, the Soviets spent massive sums of money to develop and procure their current force of multiple and single warhead ICBMs and submarine launched ballistic missiles. To ensure adequate penetration of a U.S. space missile defense force, the Soviets would have to rebuild missiles with hardened skins or deploy more missiles--at considerable cost.

There are also potential U.S. countermeasures to protect U.S. space weapons against Soviet attack. For example, U.S. space weapons could be hardened against nuclear effects, such as electromagnetic pulse. It is a long way from the "back of the envelope" design of countermeasures to deployment of a cheap effective capability. There are, for example, countermeasures to tanks such as anti-tank guns, missiles, mines, and other weapons (many much cheaper than tanks), yet tank forces still win battles. The Defense Technologies Study Team reviewed a wide range of possible Soviet counters to U.S. space defense weapons. It concluded that an effective space anti-missile defense is still achievable and affordable. While the DTST may be wrong, it is too early in the development of space weapons for confident assessments that space weapons are not cost-effective. The history of military technology is replete with false predictions about the lack of feasibility and ineffectiveness of various weapons systems. Certainly, the military potential of space weapons justifies a well-funded program of research, development, and testing.

Space Weapons and Stability

Many critics of space weapons worry that U.S. deployment of such systems would be "destabilizing," that is, it would make war more likely. More specifically, these critics argue that:

- U.S. deployment of space weapons would create a hair-trigger situation in which each side would be tempted to attack the other side's satellites and space weapons first in time of crisis to prevent the destruction its own valuable satellites and space weapons;[40]

- Soviet leaders are likely to see U.S. space missile defense weapons as giving the U.S. a war winning capability and decide to destroy U.S. space weapons before they become fully operational;

- U.S. deployment of space weapons would intensify the arms race, as each side deployed weapons to prevent the other side from achieving military superiority. The result is increased superpower tension

Stability is a proper concern of U.S. defense planners, but these arguments are based on some questionable assumptions.

It is, of course, quite possible that the U.S. can protect its satellites and space weapons from Soviet attack. As long as U.S. defensive systems were reasonably secure, the Soviets would be less certain of military success and thus less likely to strike in a crisis situation. However, even if the U.S. deployed space weapons with a reasonable degree of confidence in their effectiveness and survivability, there would be a possibility that the Soviets could develop unforeseen countermeasures that would place those space weapons in jeopardy. Even this development would not necessarily be destabilizing.

First, space defense weapons complement strategic nuclear offensive forces but do not replace them. The U.S. should maintain retaliatory forces that are survivable in their own right. Thus even if the Soviets could overcome U.S. defenses, they would still face a retaliation in kind to the full spectrum of attacks they might launch.

Second, given the direction of recent Soviet research and development and the significance of strategic defense in Soviet doctrine, it is likely that the Soviets will attempt to deploy a force of space-based missile defense weapons, particularly if the U.S. does so. If both sides' space weapons are vulnerable, the result is not destabilizing. Mutual vulnerability of offensive nuclear weapons is destabilizing. The existence of defensive systems (vulnerable or not) means that, if war should come, the first shots would inevitably be fired in space, thereby providing an additional threshold to be crossed prior to the use of nuclear weapons. This threshold would provide additional time to communicate with the Soviets to try to stabilize a crisis. Chances for successful U.S. retaliation would also increase by providing additional reaction time for time sensitive U.S. strategic offensive forces, such as bombers. Deterrence should thus be strengthened as well. Provided the U.S. maintains a sufficient offensive deterrent, the USSR should have no incentive to attack U.S. defense systems, even if they were vulnerable.

The argument has also been made that ASAT weapons would destabilize a crisis situation because the destruction of communications and intelligence satellites would diminish the intelligence, command, and communication capabilities necessary to control escalation. Even with the advent of more capable ASAT weapons, this argument is flawed. An attack on U.S. satellites would be an act of extreme provocation that would make sense only in the context of a larger conflict. In a lower level crisis there would be little or no incentive to attack satellites, thus leaving U.S. crisis control assets intact. Even if the Soviets should attack U.S. satellites in a lower level crisis, there would be little chance of unjustified U.S. nuclear escalation. Current U.S. policy is not to retaliate with strategic nuclear forces until there is absolute confirmation of nuclear attack, that is, nuclear

explosions in the U.S. The destruction of U.S. satellites, however provocative, should not trigger U.S. nuclear retaliation.

Futhermore, deployment of new ASAT weapons will not take place in a vacuum; U.S. countermeasures (such as passive survival aids, active defenses, and more reliance on high altitude remotely piloted vehicles) can help ensure an adequate flow of information. It also seems odd that those arguing against ASAT weapons on the grounds of their effect on crisis stability are often opposed to strategic defense (which is designed to control escalation and limit damage) and wedded to MAD, a strategy that, in the event of a deterrence failure, logically ends in the deliberate execution of millions of people--hardly a model of escalation control.

The truly extraordinary suggestion has been made that the mere prospect of deployment of ballistic missile defense systems might trigger World War III.[41] The odds that the Soviets would strike preemptively if faced with U.S. deployment of space defense weapons are, fortunately, extremely low. U.S. deployment of space weapons does not directly threaten the Soviet Union. It would tilt the strategic balance in favor of the U.S. only if the Soviets did nothing. A balance would be maintained, however, if the Soviets deployed a comparable defense capability. For any rational Soviet leaders, mutual survivability of the superpowers through space defense should be preferable to nuclear war.

The argument that U.S. deployment of space weapons would fuel the arms race assumes falsely that the current Soviet military activity buildup is in reaction to U.S. weapons programs. But as Jimmy Carter's Secretary of Defense Harold Brown has pointed out, "When we build, the Soviets build. When we don't build, the Soviets build."[42] Twenty years ago, the Soviet Union embarked on a defense buildup, evidently aimed at achieving overall military superiority. This has proceeded at a steady pace, undeterred by a decade of detente, SALT, and a voluntary near-freeze of its arsenal by the U.S.

What U.S. deployment of space weapons can do is redirect Soviet efforts into more stabilizing and less threatening defensive systems. Mutual deployment of strategic defenses would create a new stable order in which the Soviet Union would have no incentive to launch a nuclear attack against the U.S.

Space Weapons and Arms Control

Many critics of space weapons look to arms control as the primary means to deal with the Soviet military threat. Arms control, however, has failed to reduce that threat signficantly. Indeed, since the onset of strategic nuclear arms control negotiations in 1969, the balance has shifted dangerously in the direction of Soviet nuclear superiority. The U.S., therefore, must rely on its own defenses for its security. In particular, Washington should not sign an arms control agreement with the Soviet Union banning space weapons. Such an action would deprive the

U.S. of its most important means of defending the American people against Soviet missile attack.[43]

U.S. experience with the Soviets regarding earlier arms control efforts suggests that arms control would be inadequate to deal with the threat of Soviet space weapons. The Soviets consistently resist tightly worded treaty provisions. As with SALT I, the result invariably is that Moscow fully exploits treaty loopholes to continue developing weapons of strategic importance. Even within the distressingly loose constraints of flawed treaties, Soviet compliance has been poor. Specifically, the Soviets have tested SAMs in an ABM mode for upgrading air defenses for anti-ballistic missile missions, developed and tested mobile radars and missile launchers, deployed battle management radars for a nationwide ABM system, and tested rapid reload launchers--all in violation of the ABM Treaty. The Reagan Administration has just issued a report further detailing Soviet arms control violations.

Crucial to any arms treaty with the USSR is the U.S. ability to verify Soviet compliance. A U.S. State Department assessment,[44] however, finds that the arms control agreement banning the testing and deployment of space weapons recently proposed by the Soviet Union (and similar to that proposed by U.S. space arms control proponents) would not be verifiable by U.S. surveillance satellites or ground-, sea-, and air-based listening posts operating on the periphery of the USSR. These so-called national technical means of verification are the only verification instruments Moscow has approved.

Arms control advocates argue that passive measures could protect U.S. satellites against any ASAT capabilities the Soviets could develop and deploy covertly in violation of an ASAT ban. Because an ASAT ban is so difficult to verify, it would seem that the Soviets could covertly deploy space mines and ASAT missiles on manned and unmanned spacecraft, in addition to their current orbiting killer satellite. The Soviets might not be able to covertly test new generation weapons sufficiently to warrant high confidence in their capability, but such weapons might still be effective if war broke out. The effectiveness of passive measures against covert deployment of these more sophisticated ASAT weapons is very uncertain. The signing of an ASAT ban with the Soviet Union is thus very risky.

In any case, space arms control advocates overestimate the determination of the U.S. to react promptly and forcefully to Soviet treaty violations. Although the U.S. government has substantial evidence of Soviet violations of SALT agreements, Washington has failed to adjust its arms control policy and defense programs. Pressure by U.S. arms control enthusiasts, who seem intent on preserving the arms control process despite Soviet treaty violations, has made it extremely difficult for the Administration to gain congressional support for a strong U.S. response to these violations.[45]

Arms control is not an end in itself. Proposals for limiting weapons deployments must be evaluated in terms of their effect on U.S. national security and their contribution to preserving world peace. A ban on space weapons would deprive the U.S. of the means to defend itself against nuclear attack even as the Soviets continued to build up their nuclear warfighting offensive and defensive capabilities.

CONCLUSION

Security sometimes is enhanced by new kinds of weapons. Example: the U.S. deployment of missile firing submarines, which gives the U.S. a survivable force that could retaliate if the Soviets attacked U.S. cities. Likewise, space weapons would enhance U.S. security by helping protect the U.S. population and U.S. military forces from Soviet nuclear attack.

Critics of space weapons are rightly concerned about the implications of space weapons deployment for the security of U.S. satellites. Their solution--an ASAT weapons ban--however, would foreclose the option of effective strategic defense. The U.S. must do much more to protect its satellites from new Soviet ASAT weapons. A full program of passive survival aids is needed, including deployment of spare satellites in space, design of satellites with a maneuvering capability, and hardening of satellites against nuclear effects. Deployment of space laser weapons in the 1990s would provide substantial additional protection. Ultimately, in wartime, the U.S. might have to reduce reliance on satellites for military support functions.

The Defense Department currently is constructing a detailed "road map" for the development of advanced space weapons. Congress should adequately fund a research and development effort leading to testing a prototype orbiting space laser weapon by 1990 and rigorous operational testing of a space missile defense system in the 1990s. At the same time, the U.S. should proceed with the testing and deployment of the miniature homing vehicle (MHV) anti-satellite weapon. It probably has some limited value in deterring Soviet attacks on U.S. satellites, and it could be used to defend U.S. satellites against Soviet killer satellites and to deny the Soviets use of valuable space systems in a conflict. It is essential, however, that the U.S. proceed immediately to reduce the vulnerability of its strategic nuclear forces to a Soviet first strike, for nuclear weapons will remain the bedrock of deterrence for the next twenty years at least.

Space weapons are not wonder weapons capable of giving the U.S. decisive military superiority. Nor are they cheap. But their potential contribution is a new kind of security--based on protecting U.S. lives rather than leaving them hostage in a dangerous "balance of terror."

If space defense could be achieved, it would be strategically imprudent and morally irresponsible not to deploy space weapons to defend the U.S. homeland against nuclear attack.

Robert Foelber*
and
Brian Green
Policy Analysts

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* After completing work on this study, Heritage Foundation Policy Analyst Robert Foelber joined the staff of the Library of Congress' Congressional Research Service.

NOTES

1 Resolutions to de-weaponize space have been introduced in both Houses of the 98th Congress. These include: H.J. Res. 87, introduced by Representative Robert W. Kastenmeier (D.-Wis.), and H.J. Res. 120, introduced by Joe Moakley (D.-Mass.) with 76 co-sponsors, which call on the President to resume talks with the Soviet Union aimed at banning all weapons from space. (From 1977 to 1979 the U.S. and USSR met in three rounds of negotiations to discuss a ban on ASAT weapons. The talks have been suspended since the Soviet invasion of Afghanistan.) S.J. Res. 28, introduced by Sen. Paul Tsongas (D.-Mass.) is identical to the Moakley resolution. Senator Larry Pressler (R.-S.D.) has introduced S. Res. 43 calling for negotiations to ban ASAT weapons as a first step toward a comprehensive ban on all space weapons. Attempts to delete funding for testing and advanced procurement of the ASAT system from the FY 1984 defense budget were defeated by Congress, although funding for testing is contingent on a presidential certification that the U.S. is proceeding in good faith to negotiate a treaty with the Soviet Union banning ASATs or that such tests are necessary for national security.

2 In this paper, "space weapon" refers to any ground-, air-, or space-based weapon which is capable of destroying or otherwise rendering inoperable objects orbiting in or transiting space, including satellites and ballistic missiles and their warheads.

3 John Bosma, "Space and Strategic-Defensive Reorientation: Project Defender," Defense Science and Electronics, September 1983, pp. 58-65.

4 The Defense Technologies Study Team, directed by former NASA head, James C. Fletcher, was formed by the Administration to study the feasibility of space-based ballistic missile defense. The DTST's report, delivered to the White House in October, has not been made public, but for a discussion of its major findings, see Clarence A. Robinson, Jr., "Panel Urges Defense Technology Advances," Aviation Week and Space Technology, October 17, 1983, pp. 16-18; "Study Urges Exploiting of Technologies," ibid., October 24, 1983, pp. 50-57; and "Shuttle May Aid in Space Weapons Test," ibid., October 31, 1983, pp. 74-78.

5 For an analysis of Soviet nuclear doctrine, backed with copious citations from Soviet military writings, see Mark E. Miller, Soviet Strategic Power and Doctrine (Washington, D.C.: Advanced International Studies Institute, 1982) and Joseph D. Douglass, Jr. and Amoretta Hoeber, Soviet Strategy for Nuclear War (Stanford, California: Hoover Institution Press, 1979). Soviet nuclear doctrine stresses that the Soviet Union must have the capability to deliver a crushing blow to U.S. offensive nuclear forces and to defend the USSR against retaliation from surviving U.S. nuclear weapons.

6 George Wilson and Walter Pinkus "Missile Survival Questioned," Washington Post, May 9, 1983, p. 1; Harold Brown, Department of Defense Annual Report to Congress, Fiscal Year 1982, p. 111. Roughly 30 percent of the U.S. bomber force is on alert and about half of U.S. submarines are at sea at any given time; those forces would have a good chance of escaping a Soviet first strike.

7 Clarence A. Robinson, Jr., "Emphasis Grows on Nuclear Defense," Aviation Week and Space Technology, March 8, 1982, p. 36.

8 Director of Central Intelligence, Soviet Civil Defense (N178-10003), July 1978. Department of Defense, Soviet Military Power (Washington, D.C.: Government Printing Office, 1983), p. 30.

9 See Carnes Lord, "The ABM Question," Commentary, May 1980, p. 34, and Robert P. Berman and John C. Baker, Soviet Strategic Forces: Requirements and Responses (Washington, D.C.: The Brookings Institution, 1983), p. 149.

10 Soviet ABM upgrades are discussed in "Soviets Test Defense Missile Reload," Aviation Week and Space Technology, March 8, 1983, p. 27, and Berman and Baker, op. cit., p. 149.

11 Clarence A. Robinson, Jr., "Soviets Accelerate Missile Defense Efforts," Aviation Week and Space Technology, January 16, 1984, pp. 14-16; Michael Getler, "Soviets Seen Progressing Toward a Missile Defense System," Washington Post, January 20, 1984, p. A25.

12 Laser weapons involve highly concentrated beams of light (photons) generated by a number of means including chemical reactions between hydrogen and fluoride gases (chemical lasers), exciting molecules of inert gases with electricity ("excimer" lasers), amplifying a laser beam with an electron beam (free electron lasers), or pumping a solid material with X-rays or gamma rays generated from a nuclear explosion. The different lasers produce different beams of different wavelength and strength. Laser weapons kill their targets by heating them, shock wave propagation, radiation, or a combination of these processes.

Particle beam weapons "work by accelerating subatomic particles--neutrons, electrons, or protons (a charged particle beam) or ionized hydrogen atoms (a neutral particle beam) at speeds approaching that of light, in very large quantities, creating an energy beam with a very high-energy density. Such a beam can best be described as a manmade lighting bolt which, upon reaching its target, shatters the surface and then penetrates deeply, thereby depositing its energy in a long narrow cone throughout the target." Kenneth Harmon, "Directed Energy Weapons," Grand Strategy: Countercurrents, August 15, 1982, pp. 2-8.

13 Craig Corvault, "Soviet Antisatellite Treaty Raises Verification Issue," Aviation Week and Space Technology, August 29, 1983, p. 20.

14 Soviet Military Power, p. 68.

15 "Soviet Tracking," Aviation Week and Space Technology, October 25, 1982, p. 15.

16 "Soviets Build Directed Energy Weapon," Aviation Week and Space Technology, July 28, 1980, pp. 47-50.

17 For a more detailed statement of these arguments, see Robert Foelber, "Strategic Defense: Avoiding Annihilation," Heritage Foundation Backgrounder No. 304, November 9, 1983.

18 For a classic statement of U.S. nuclear doctrine, formulated during the Carter Administration in Presidential Directive-59 and reaffirmed by the Reagan Administration, see Harold Brown, Department of Defense, Annual Report Fiscal Year 1981, p. 66.

19 For a discussion of Soviet ASAT doctrine, see Lawrence Freedman, "The Soviet Union and 'Anti-Space Defence,'" Survival, July-August 1977, pp. 16-23. In 1964, the USSR established a special anti-space branch of its air defense force "to destroy space systems used by the enemy for military purposes, in their orbits" using "special spacecraft and vehicles (e.g.,

satellite-interceptors), which may be controlled either from the ground or by special crews." Quoted in Freedman, p. 18.

20 The June 1982 test involved an anti-satellite test, two ICBM launches, an SS-20 launch, an SLBM launch, and two ABM firings simulating, according to some U.S. analysts, in logical sequence a first-strike against U.S. ICBMs coupled with an attacked against U.S. satellites, followed by defense against U.S. retaliatory strikes and a follow-up second strike against the U.S. using SLBMs. "Soviet Stage Integrated Test of Weapons, Aviation Week and Space Technology, June 28, 1982, pp. 20-21.

21 From 1963 to 1970, the U.S. experimented with two crude ASAT weapons--Thor and Nike-Zeus missiles armed with nuclear warheads. The Thor system was decommissioned in 1975, the Nike-Zeus in 1967. Presumably, the Soviet Union also has the capability to launch nuclear missiles at satellites. The Soviets claim that they have never tested ASAT weapons and that U.S. claims that the USSR has an operational ASAT system are "mythical." For a brief discussion of Soviet efforts to "disinform" the West about Soviet space weapons programs, see James E. Oberg, "Andropov's Orbiting Bombs: The Soviets' Outer-Space 'Peace' Strategy," Reason, December 1983, pp. 25-30.

22 The "near orbit" approach, whereby the killersat performs a "pop up" maneuver to bring it into close proximity to the target, is militarily the most effective approach, since attacks can be more easily disguised.

23 "Soviets Outspending U.S. On Space by $3-4 Billion," Aviation Week and Space Technology, July 19, 1982, pp. 28-29.

24 Covault, op. cit., p. 20.

25 David Baker, The Shape of Wars to Come (New York: Stein and Day, 1982), p. 167.

26 The difficulties of arms control as a method of securing U.S. space assets are discussed in greater length later in this paper; see also Colin Gray, op. cit., pp. 49-55.

27 Passive survival aids for satellites include: harden systems against nuclear effects, especially the electromagnetic pulse (EMP) phenomenon which can render electronic circuits inoperable, build maneuvering satellites that can evade Soviet ASAT weapons, stockpile spare satellites on the ground in high orbits in an inert state to be called down and activated in time of war, equip satellites with radar and infrared spoofing devices to provide false signatures to Soviet sensors, deploy decoy satellites, and equip satellites with umbrellas to deflect laser beams. For a discussion of threats and survival aids for U.S. satellites, see Robert B. Giffen, U.S. Space System Survivability: Strategic Alternatives for the 1990s (Washington, D.C.: National Defense University Press, 1982). Presidential Directive-37, signed in 1978, called for greater survivability of U.S. satellites.

28 This has led some space analysts, including military officers responsible for U.S. satellites, to favor an arms control agreement with the Soviet Union banning the testing and deployment of ASAT weapons. Civilian space arms control advocates tend to favor a treaty that would prevent the U.S. from testing and deploying its new ASAT weapon. Some military arms control advocates want to restrict only the testing and deployment of more advanced ASAT weapons.

29 For a description of Soviet satellites and the argument that loss of Soviet satellites would not constitute a major reduction in Soviet war-fighting capability, see Stephen M. Meyer, "Soviet Military Programmes and the 'New High Ground,'" Survival, September-October 1983, pp. 204-215. Colin S. Gray argues that Soviet dependence on satellites for successful nuclear operations is still considerable. American Military Space Policy: Information Systems, Weapons Systems, and Arms Control (Cambridge, Mass.: Abt Books, 1983).

30 "Anti-Satellite Weapons and Arms Control," Arms Control Today, December 1983, p. 1.

31 For example, U.S. airborne command posts can only stay aloft for 72 hours, even with air-to-air refueling, before they must land for brief maintenance. With defenses against Soviet missiles, the U.S. could selectively defend a certain number of airstrips to keep airborne command posts operating.

32 Soviet RORSATs use active radars powered by nuclear generators to detect U.S. surface naval vessels. EORSATs passively listen in on electronic emissions (radars, communications) to detect the location of surface vessels and possible submarines as well. Berman and Baker, op. cit., pp. 162-164. Robert Cooper, DARPA Director, has called Soviet ocean satellites "a major new threat" to U.S. naval forces. "Navy Warned of New Soviet Threat," Chicago Tribune, March 18, 1982, p. 5.

33 "Major aspects of the Soviet manned space programme are exclusively military. For example, it is well known that the Salyut space station has been outfitted in and tasked in two distinct versions: one for military missions and one for civilian missions. A wide range of reconnaissance, ELINT (electronic intelligence), and C3 (command-control-communications) tasks and experiments have been performed by Soviet cosmonauts during extended says in space....In 1981-2 cosmonauts were in orbit 286 days..." Meyer, op. cit., pp. 204-205. By contrast, the U.S. did not have a man in space from 1975-1981 and the U.S. record for space endurance is only 84 days vs. 211 for the Soviets. The Soviet Union is now developing a huge space station to be manned by 12-20 cosmonauts who could assist in constructing space weapons. "Soviets Outspend U.S. On Space by $3-4 Billion," Aviation Week and Space Technology, July 19, 1982, pp. 28-29.

34 The Soviets appear to be developing two versions of a space plane. The first is a small 2,000 pound unmanned orbiter which could be a more flexible weapon system than the Orbital and Fractional Orbital Bombardment Systems tested by the Soviets in the 1960s. The second Soviet space plane resembles the U.S. shuttle and could be ready for regular use within ten years. See Thomas O'Toole, "Soviet Test in Space May Be A-Weapons," Washington Post, March 17, 1983, p. A13; and James E. Oberg, "The Elusive Soviet Space Plane," Omni, September 1983.

35 For a brief account of the beginnings of the U.S. ASAT program, see U.S. Senate, Committee on Commerce, Science, and Transportation, Soviet Space Programs: 1976-1980 (Washington, D.C.: Government Printing Office, 1982), pp. 184-186.

36 Clarence A. Robinson, Jr., "Panel Urges Defense Technology Advances," Aviation Week and Space Technology, October 17, 1983, pp. 16-18.

37 Charged particle beam weapons would not work in space because the beams would be bent by the earth's magnetic field.

38 General Daniel O. Graham, High Frontier: A New National Strategy (Washington, D.C.: High Frontier Inc., 1982).

39 Daniel Kaplan, "Lasers for Missile Defense," The Bulletin of Atomic Scientists, May 1983, pp. 5-8.

40 A recent publication of the Center for Defense Information, for example, states: "Space weapons which threaten satellites increase incentives for a first strike. If both sides could suddenly lose their vital military satellites--and therefore much of their military capability--there is great pressure, especially in a crisis situation to launch nuclear weapons before the opportunity to do so is lost." "Militarizing the Last Frontier: The Space Weapons Race," The Defense Monitor, Vol. XII, Number 5, p. 7.

41 According to a publication of the Union of Concerned Scientists, "even the mere prospect of ABM deployment could spark hostilities. The imminent deployment of ABMs could temp an enemy to attack suddenly and decisively to disarm its opponent." The New Arms Race: Star Wars Weapons (Briefing Paper No. 5), p. 5.

42 Joyce Larson and William Bodie, eds., The Intelligent Layperson's Guide to the Nuclear Freeze and Peace Debate (New York: National Strategy Information Center, 1981), p. 19.

43 Space basing is required for a BMD system designed to intercept ballistic missiles in their flight. The most recent draft treaty proposed by the Soviet Union seeks to prohibit deployment and/or testing of space-based weapons "designed to hit targets on the Earth, in the air and in outer space." This presumably would exclude the Soviet ground-based ASAT weapons, but surely would include any space basing of U.S. ballistic missile defenses. A draft treaty by the Union of Concerned Scientists bans the deployment and testing of any ASAT weapons anywhere. It is difficult to conceive of a BMD system that would not have some ASAT capability also; to argue that the purpose of ASAT and BMD weapons is different does not change the inherent technological overlap. A copy of UCS treaty may be found in the Congressional Record, May 18, 1983, pp. S6991-6993.

44 Covalt, op. cit., pp. 20-22.

45 The deleterious effect on U.S. security of the lack of a coherent and determined compliance policy is discussed in "Soviet Treaty Violations and U.S. Compliance Policy," National Security Record, a monthly publication of The Heritage Foundation, December 1983.

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MARCIA S. SMITH

The Militarization of Space and Other International Space Issues

From August 9-21, 1982, the United States and 93 other countries participated in the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space in Vienna, Austria. The conference was held under the auspices of the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS) with the goal of assessing methods for assisting developing countries to benefit from space activities to the maximum extent possible. The conference turned out to be primarily a drafting committee for developing a final report for transmittal to the U.N. General Assembly, rather than a demonstration of the potential benefits of space activities. Among the most controversial issues discussed were: military uses of space; access to geostationary orbit; principles for remote sensing and direct broadcast satellites (DBS); technology transfer; and creation of a U.N. Centre for Outer Space.

PREPARATORY ACTIVITIES

The United Nations General Assembly scheduled UNISPACE'82 in 1980, thus giving all nations approximately two years to prepare for the conference. The conference secretariat, headed by Yash Pal of India, was charged with developing a draft conference report, for initial consideration by COPUOS and final approval at the conference. The 53 members of COPUOS were invited to submit national papers to provide input to the draft report. Once approved by the conference, the report would be transmitted to the General Assembly for action.

COPUOS is serviced within the U.N. organization by the Outer Space Affairs Division (OSAD). In 1980, the director of OSAD, a Czechoslovakian, retired and the United States expected that his deputy, an American, would assume that position. Early in 1981, however, it became apparent that the Soviet Union would insist that another Czechoslovakian be installed as OSAD Director. The United States objected to this, and to emphasize its position, anncunced that it would not participate in some of the preparatory activities for UNISPACE until the American was named Director. This dispute was not resolved until December 28, 1981, so for the entire year, the United States did not formally participate in UNISPACE preparations (for example, it did not submit a national paper or name a deputy-secretary general, and for several months, blocked publicity efforts for the conference).

The issue was finally resolved when outgoing U.N. Secretary General Kurt Waldheim decided that the American would serve as Acting Director until UNISPACE commenced, and then officially would become Director. The Czech would be his deputy and become Director once the American retires (in the spring of 1983).

As a result of this personnel dispute, the United States did not begin its preparatory activities until early 1982, only seven months before the conference. A State Department coordinator was named in March (Ambassador Gerald Helman) and soon thereafter James Beggs, Administrator of NASA, was named chairman of the delegation. The other members were not named until the end of July, however, two weeks before the conference. This precipitated concern in Congress that the delegation would not be prepared to deal with the issues which were likely to arise at UNISPACE.

One problem in this regard was that the United States insisted that UNISPACE was a technical conference, charged with dealing with technical issues such as remote sensing technology, and not with political issues such as the desire by many countries to have the right of "prior consent" over who has access to data obtained with remote sensing satellites and over what programming is beamed into their territory by direct broadcast satellites.

THE ISSUE OF "MILITARIZATION" OF SPACE

It also became apparent prior to the conference that a major topic of discussion would be the political issue of the increased military uses of space. This topic has been assigned to the U.N. Committee on Disarmament rather than COPUOS, so was not on the formal agenda of UNISPACE, but the 430 paragraph draft conference report which had been prepared by the UNISPACE'82 secretariat contained four paragraphs concerning the "militarization" of space.

During meetings in early 1982, COPUOS members reached agreement on all but 15 of the paragraphs in the draft report. The four on militarization were among the 15

THE RESULTS OF THE UNISPACE'82 CONFERENCE

that were bracketed to indicate they remained in disagreement. Since UNISPACE'82 had to reach final agreement on the entire report, it was clear that militarization would have to be discussed. Nevertheless, U.S. delegation leaders insisted that this would not be a major topic of discussion.

Opening Session of the Conference

Anyone who still believed that militarization of space would not be a focus at UNISPACE'82 would have been rudely surprised at the opening session. The first three speakers—U.N. Secretary General Javier Perez de Cueller, Austrian President Rudolph Kirchshlaeger, and Austrian Foreign Minister Willibald Pahr (who also served as President of the conference)—all mentioned the topic prominently in their initial remarks. For the remainder of the first week, 67 countries presented opening statements in the plenary sessions, and all but 4 (including the United States) mentioned militarization.

Proposed Working Group

At the beginning of the conference, Pahr suggested that a working group be established to deal with the four bracketed paragraphs on militarization so as not to hold up the work of the three committees which had been established to develop final wording in the draft report. The United States and the Soviet Union objected to this proposal, so no working group was created and the task of resolving this issue fell to the three committees. In order to expedite their work, the committees decided in turn to defer the militarization issue (together with other very controversial topics).

Committee 1 Debate

The first debate on militarization therefore did not occur until the second Monday at a special evening session of Committee 1. After an hour's debate on this topic, it appeared that agreement had been reached on the first sentence, but just as the committee chairman banged the gavel to indicate that the sentence had been adopted, the chief U.S. spokesman at that meeting informed the chairman that he could not accept any of wording that had been proposed.

Later he added that it was actually the "concept" to which he objected, not just the wording, so no language would be acceptable. Since it was apparent that consensus would not be reached that evening, the committee session was adjourned.

Final Resolution

Now that it was clear that the committees would not be able to deal with the issue, Pahr once again proposed creation of a working group; this time it was accepted. The group, called "Friends of the President," was established on Wednesday morning, and by Friday morning consensus had been reached on three paragraphs discussing the international concern over the potential arms race in space. This phrasing was a partial victory for the United States, which objected to the word "militarization" because it includes all military space activities (such as reconnaissance and communications) and not just the use of weapons in space. Why the United States did not suggest this wording at the Monday meeting, rather than standing alone in its opposition to all wording on military uses of space, is unclear. The three paragraphs were subsequently adopted by the conference as a whole.

OTHER CONTROVERSIAL ISSUES

In addition to militarization, there were several other very controversial topics discussed at UNISPACE, both those in bracketed paragraphs and those on which agreement had been reached within COPUOS. The major issues were: geostationary orbit, prior consent for remote sensing and direct broadcast satellites, technology transfer, and creation of a U.N. Centre for Outer Space.

Geostationary Orbit

Geostationary orbit (GEO) exists 35,800 kilometers above the equator, and an object placed there will retain a fixed position relative to a point on Earth. It is therefore extremely useful for space applications such as communications satellites.

Developing countries want special "*a priori*" planning schemes to be instituted which will reserve places in GEO for all countries, because they are concerned that the "good" slots and frequencies will be assigned to developed countries under the existing "first-come, first-served" scheme. The United States and other developed countries object to *a priori* planning because it could prevent use of various parts of the orbit and certain frequencies, even though there are no guarantees that a particular developing country would ever use them. They also point out that assignments are given only for the lifetime of a particular satellite, not in perpetuity, and that technological advances may render the problem moot by the time developing countries want to use the slots.

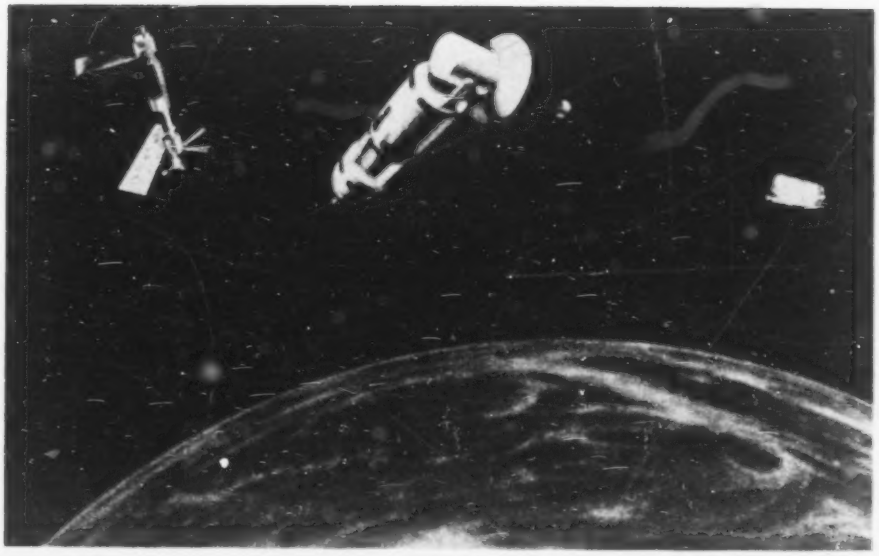
Another aspect of the GEO debate is that many of the equatorial countries want to be given special consideration in use of GEO because of their geographical position vis-a-vis that orbit. At UNISPACE, efforts by these countries to add language giving them special consideration were partially rebuffed by other countries, such as those at far northern latitudes where receiving signals from GEO satellites is difficult, who also feel they deserve special consideration.

The conference adopted wording stating that future planning schemes for GEO will take into account the needs of developing countries and the needs of countries "in special geographical positions."

Prior Consent

COPUOS has been debating proposed principles to govern international remote sensing and direct broadcast satellite (DBS) activities for more than a decade without resolution. Attempts were made by several countries at UNISPACE'82 to add language stating that a country

Marcia S. Smith is a specialist in aerospace and energy systems, Science Policy Research Division.



Artists concept of spaceborne laser weapon.

DOD

should have the right of prior consent over the distribution of data about itself from remote sensing satellites, and over the transmission of programming into its borders by DBS. These attempts were rebuffed, although language was added about the possible impact of these activities on national sovereignty, and stating that "it is now time" for agreement to be reached on principles governing these activities.

A new facet of the remote sensing issue arose at UNISPACE'82. Many developing countries wanted language stating that a sensed country should have priority access at a nominal cost to all data and information obtained about itself from remote sensing satellites. Compromise language was developed which states that sensed countries shall have "timely" access to all primary data (not data and information) under "reasonable conditions."

Technology Transfer

Developing countries wanted the UNISPACE conference report to call on developed countries to provide increased assistance to them and for greater international cooperation in space. The United States and other developed countries wanted language stating that developing countries have to take more responsibility for themselves. The final conference report reflects both points of view.

Centre for Outer Space

The original draft of the UNISPACE conference report had contained a recommendation that a new U.N. Centre for Outer Space be created to take over and expand the activities of OSAD. During preparatory actions on the draft report, this was toned down in response to concerns of the United States and other countries that such a move would require an increase in contributions to the U.N. assessed budget. Wording was added to the draft report that if such a Centre were to be created, most of the funding would come from voluntary contributions.

At the conference, this was further diluted, such that the final report simply states that either a new Centre could be created or the activities of OSAD could be expanded, and refers the matter to the General Assembly for consideration.

AFTERMATH OF THE CONFERENCE

UNISPACE'82 was supposed to be a conference concerned with helping the developing countries benefit from space activities. Whether or not this was accomplished is difficult to ascertain. Because the conference turned out to be primarily a drafting committee for developing final language for the report, delegates had little time to visit the exhibits or attend special demonstration sessions sponsored by the United States on programs such as Landsat, Space Telescope, and communications satellites.

On the positive side, however, 94 countries attended the conference, many of which were developing countries that are not members of COPUOS and therefore probably were not highly aware of activities in the space field. Their exposure to the issues, technical and political, will probably prove to be advantageous to them in the future.

The conference report, which contains the observations and recommendations of the countries attending the conference, will be considered by the General Assembly in

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its 1982 session. Since the report was arrived at by consensus, however, the recommendations are not strongly worded and probably will have little impact on space policies and programs.

Perhaps of more potential significance are two statements issued by the Group of 77 (a group of developing nations which is now composed of 120 countries) at the conference. Although they are not part of the official report, these strong views cannot be ignored since they represent so many nations. On militarization, the Group of 77 called on the two space powers to begin negotiations immediately on a ban on the testing, development, and use of all weapons in space.

As noted earlier, this issue has been referred to the U.N. Committee on Disarmament (CD). The U.S. position—that militarization should not be discussed at UNISPACE'82 because it has been assigned to the CD—was weakened by the fact that the United States opposes creation of a working group in the CD to deal with this issue (all other nations in the CD want such a group established). Whether UNISPACE will change the U.S. position is unclear, although the CD was meeting at the same time as UNISPACE'82, and there was no noticable shift.

Another aspect of this is whether militarization should be referred to COPUOS as well as to the CD, a matter which may be considered by the General Assembly this year.

Regarding remote sensing and DBS, the Group of 77 called on the United Nations to seek final approval of principles governing these space activities, and recommended that prior consent be one of those principles. The United States opposes prior consent because of its belief in free flow of information and freedom of speech. Draft principles on DBS may come up for a vote in the U.N. General Assembly this fall.

CONGRESSIONAL INTEREST

Prior to UNISPACE, the House Science and Technology Committee and the House Foreign Affairs Committee held hearings on U.S. preparations for the conference. Concern was focussed on whether the U.S. was adequately prepared for both the technical and political issues likely to arise.

Five members of Congress attended portions of the conference: Rep. Ronnie Flippo, chairman of the Subcommittee on Space Science and Applications of the House Science and Technology Committee; Rep. Daniel Akaka, Co-Chairman of the Congressional Space Caucus; Reps. George Brown and William Carney, members of the House Science and Technology Committee; and Rep. Wayne Grisham. In addition, staff members from the House Science and Technology and House Foreign Affairs Committees, the Congressional Research Service, and the Office of Technology Assessment, attended all or part of the conference.

Some of the issues of continuing congressional concern now that the conference is over include: an assessment of U.S. performance at the conference, particularly in terms of how well the major issues were anticipated; composition of the U.S. delegation to the conference and why the members were named only two weeks before the meeting convened; and what the U.S. position should be at the United Nations concerning the issue of military uses of space.

Hearings may be held this late fall either on UNISPACE specifically or on the general topic of U.S. space policy, at which UNISPACE is likely to be discussed.

Suggested Reading:

Smith, Marcia S. Antisatellites (Killer Satellites). Issue Brief 81123.

_____. Space Policy and Funding: NASA and DOD. Issue Brief 78058.

_____. UNISPACE'82: The Second U.N. Conference on Outer Space. Mini-Brief 82231.

U.S. Office of Technology Assessment. UNISPACE'82: A Background Report. July 14, 1982.

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Directed Energy Missile Defense in Space

Background Paper

April 1984

Prepared under contract for the
Office of Technology Assessment

by Ashton B. Carter
Massachusetts Institute of Technology

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

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1245

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by Ashton B. Carter
Massachusetts Institute of Technology

OTA Background Papers are documents containing information that supplements formal OTA assessments or are outcomes of internal exploratory planning and evaluation. The material is usually not of immediate policy interest such as is contained in an OTA Report or Technical Memorandum, nor does it present options for Congress to consider.

CONGRESS OF THE UNITED STATES
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Washington, D.C. 20510

Preface

This background paper was prepared by Dr. Ashton B. Carter under a contract with the Office of Technology Assessment. OTA commissions and publishes such background papers from time to time in order to bring OTA up to date on technologies that are the subject of frequent congressional inquiry. After Dr. Carter's work was under way, Senators Larry Pressler and Paul Tsongas of the Senate Foreign Relations Committee requested that the resulting paper be made available to that Committee as soon as possible. OTA is issuing the paper in the belief that others in Congress and members of the public will find it of interest and importance.

An OTA background paper differs from a full-fledged technology assessment. Background papers generally support an ongoing assessment of broader scope or explore emerging technological issues to determine if they merit a fuller, more detailed assessment. On March 22, 1984, the Technology Assessment Board directed OTA to carry out a full-fledged assessment of "New Ballistic Missile Defense Technologies," for which this background paper will serve as one point of departure.

This paper was prepared for OTA's International Security and Commerce Program, under the direction of Lionel S. Johns (Assistant Director, Energy, Materials, and International Security Division) and Peter Sharfman (Program Manager).

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Section 1
INTRODUCTION

This Background Paper describes and assesses current concepts for directed-energy ballistic missile defense in space. Its purpose is to provide Members of Congress, their staffs, and the public with a readable introduction to the so-called "Star Wars" technologies that some suggest might form the basis of a future nationwide defense against Soviet nuclear ballistic missiles. Since these technologies are a relatively new focus for U.S. missile defense efforts, little information about them has been readily available outside the expert community.

Directed-energy or "beam" weapons comprise chemical lasers, excimer and free electron lasers, nuclear bomb-powered x-ray lasers, neutral and charged particle beams, kinetic energy weapons, and microwave weapons. In addition to describing these devices, this Background Paper assesses the prospects for fashioning from such weapons a robust and reliable wartime defense system resistant to Soviet countermeasures. The assessment distinguishes the prospects for perfect or near-perfect protection of U.S. cities and population from the prospects that technology will achieve a modest, less-than-perfect level of performance that will nonetheless be seen by some experts as having strategic value. Though the focus is technical, the Paper also discusses, but does not assess in detail, the strategic and arms control implications of a major U.S. move to develop and deploy ballistic missile defense (BMD).[1]

This Background Paper grows indirectly out of President Reagan's celebrated television speech of March 23, 1983, in which he called for a "long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles."[2] Pursuant to the President's speech, the Department of Defense established a Defensive Technologies Study Team under James C. Fletcher (of the University of Pittsburgh) to prescribe a plan for the R&D program. A parallel effort, called the Future Security Strategy Study and headed by Fred S. Hoffman (of Research and Development Associates), addressed the implications for nuclear policy of renewed emphasis on BMD. This Paper covers the same technologies and issues as these Defense Department studies. The ABM Treaty reached at SALT I[3] severely restricts the development, testing, and deployment of BMD systems. Though this Background Paper treats the strategic roles of missile defenses, including many of their arms control implications, it does not treat the vital international political implications of a major U.S. move to BMD.

Focused on directed-energy intercept of missiles in their boost phase, i.e., on "Star Wars" proper, this Paper does not analyze midcourse and reentry BMD systems or non-BMD applications of directed-energy weapons.[4] "Star Wars" efforts generally further concentrate on intercept of intercontinental ballistic missiles (ICBMs) rather than the related but somewhat different problems of intercept of submarine launched ballistic missiles (SLBMs) or intermediate-range ballistic missiles (IRBMs). This Paper is therefore not a substitute for a more complete treatment of the entire subject of BMD.[5] Moreover, BMD itself is only part of the larger subject of strategic defense, comprising defense against bombers and cruise missiles, civil defense, passive defense of military targets, anti-submarine warfare (ASW), and preemptive counterforce attack in addition to BMD.

[1] BMD is the most common of four roughly equivalent acronyms covering defense against nuclear ballistic missiles. Such defenses were formerly called anti-ballistic missile (ABM) systems, but this designation fell out of favor after the debate over and eventual demise of the Sentinel and Safeguard ABM systems in the late 1960's and early 1970's. BMD largely replaced ABM as the term of choice, but recently the more self-explanatory Defense Against Ballistic Missiles (DABM) has gained popularity. Within the Executive Branch, BMD efforts pursuant to President Reagan's so-called "Star Wars" speech are referred to as the Strategic Defense Initiative (SDI). Normally the term strategic defense comprehends other methods for limiting damage from nuclear attack besides BMD.

[2] The relevant portions of President Reagan's speech are reproduced in Appendix A.

[3] The ABM Treaty and related documents are reproduced in Appendix B.

[4] Appendix C describes briefly, but does not assess, other proposed military applications of directed-energy weapons.

[5] For a more complete treatment, see *Ballistic Missile Defense*, ed. Ashton B. Carter and David N. Schwartz (Brookings, 1984).

It is unusual for the President to express himself on, and for the Congress and public consequently to concern themselves with, long-term research and development. "Star Wars" is thus a somewhat unusual subject for a technology assessment intended for a public policy audience. It is in the nature of this subject that unknown or unspecified factors outweigh what is known or can be presented in concrete detail. Many of the technologies discussed in this Paper, and most certainly all of the schemes for fashioning a defense system from these technologies, are today only paper concepts. In the debate over the Safeguard ABM system a decade ago, or over basing modes for the MX missile in recent years, one could analyze in detail the technical properties of well-defined systems in engineering development. So vague and tentative are today's concepts for "Star Wars" BMD that a comparable level of analysis is impossible. Fashions and "front runners" are likely to change. Nonetheless, one is faced with assessing the concepts receiving attention today within the Executive Branch and which underlie the President's Strategic Defense Initiative. Fortunately, judgments deduced from generic properties of these concepts, which are unlikely to change, are sometimes telling.

This Paper is based on full access to classified information and studies performed for the Executive Branch. But it turns out that a fully adequate picture of this subject can be presented in unclassified form. One reason is that the important features of the directed-energy BMD concepts are based on well-known physics, and many have in fact been discussed for 20 years. The second reason is that at this early stage of conceptualization there is simply no point in (and little basis for) discussion at the detailed level where classified particulars make a difference. The properties of actual weapon systems in engineering development, by contrast, are normally and understandably classified.

The author and OTA wish to thank officials of the Army's Ballistic Missile Defense Systems Command (BMDSCOM), the Lawrence Livermore National Laboratory, the Los Alamos National Laboratory, the Defense Advanced Research Projects Agency (DARPA), the Sandia National Laboratory, the Air Force Weapons Laboratory (AFWL), the Office of the Secretary of Defense (OSD), and the Central Intelligence Agency (CIA) for their hospitality and cooperation. Many individuals aided the research for this Background Paper, though none shares the author's sole responsibility for errors of fact or judgment. The author and OTA wish especially to thank Hans Bethe, Richard Briggs, Al Carmichael, Albert Carnesale, Paul Chrzanowski, Robert Clem, Sidney D. Drell, Dick Fisher, John Gardner, Richard L. Garwin, Ed Gerry, Jack Kalish, Glenn A. Kent, Louis Marquet, Michael M. May, Tom Perdue, Theodore A. Postol, George Rathjens, Victor Reis, Jack Ruina, George Schneiter, David N. Schwartz, Robert Selden, Leon Sloss, Daryl Spreen, Robin Staffin, John Steinbruner, Sayre Stevens, Thomas Weaver, Stephen Weiner, and Wayne Winton.

This Background Paper contains information current as of January 1, 1984.

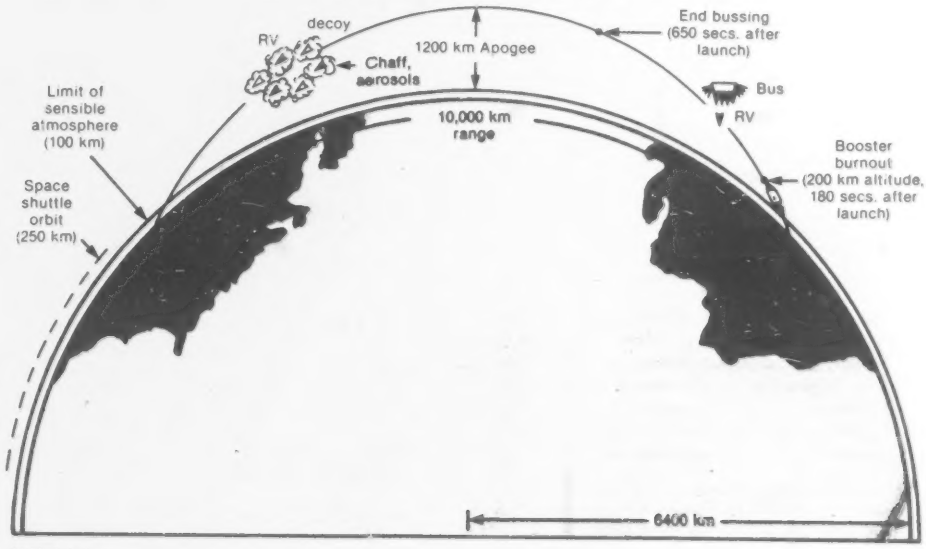
Section 2
BOOSTER CHARACTERISTICS

Intercept of ICBMs in their boost phase offers advantages and disadvantages relative to intercept of reentry vehicles (RVs) later in the trajectory. The boosters are fewer and generally more easily disrupted or destroyed than the RVs. Decoy boosters would have to match an ICBM's huge heat output, making this offensive tactic attractive only in certain circumstances. The disadvantages of boost phase intercept are that boost phase is only a few minutes long and comprises the earliest stage of an attack, and that sensing and intercept must be accomplished from outer space and over enemy territory.

Figure 2.1 shows an ordinary (minimum energy) trajectory of a hypothetical future Soviet ICBM that has been given, for illustration, the boost profile of the U.S. MX Peacekeeper. Pressure from a steam generator expells the missile from its storage cannister. Once clear of the cannister, the missile ignites its first stage motor. The first stage burns for about 55 seconds, burning out at an altitude of about 22 kilometers. The second stage also burns for 55 sec, burning out at 82 km. The third stage burns for 60 sec and carries the remainder of the missile to about 200 km, the altitude of the lowest earth orbiting satellites.

When the third stage is jettisoned at the end of the 3-minute boost phase, the remainder of the missile consists of the post-boost vehicle (PBV) or "bus" and its cargo of 10 reentry vehicles. At this point the bus and RVs are in ballistic free-fall flight to the United States. Even if they are disrupted in some way or destroyed, these objects or their debris will reenter the atmosphere over the United States. The last few seconds of third stage burn are crucial for giving the payload

Figure 2.1.—The Flight of a Hypothetical Future Soviet ICBM With the Booster Characteristics of the U.S. MX Peacekeeper, Drawn to Scale



SOURCE: Author

enough speed to reach the United States, so disruption of boost phase any time right up to burnout will cause the warheads to fall far short.

For the next 500 seconds or so after burnout—almost until it reaches apogee—the bus uses its thrusters to make small adjustments to its trajectory. After each adjustment, it releases an RV. RVs released on different trajectories continue on to different targets as multiple independently targeted reentry vehicles (MIRVs). Decoys and other penetration aids for helping the RVs escape defenses later in the trajectory are deployed during busing.

The bus itself is a target of declining value as it dispenses its RVs. Destroying it early in the deployment process would obviously be useful: the RVs not yet deployed from the bus would still arrive at the United States, but perhaps nowhere near their intended targets. If cities are the targets, relatively small aiming errors might be inconsequential. In any event, tracking the bus to allow some form of intercept requires a different type of sensor from that which tracks the booster for boost phase intercept, since the bus's thrusters are small and operate intermittently. Because of its small size, the bus (or at least critical elements of it) might be more easily hardened against directed-energy weapons than the booster. For all these reasons, the value of attempting bus intercept is very unclear, and it usually does not figure prominently in BMD discussions.

From apogee, the slowest point in their free-fall trajectory, the RVs and empty bus gain speed as they fall back to earth. RVs are more resistant to damage from directed-energy weapons than boosters, and they might be accompanied by many decoys. When these objects enter the upper atmosphere at about 100 km altitude somewhat over 2 minutes before impact, they begin to heat up, and the lighter objects slow down. Still lower, below 50 km altitude and less than a minute before impact, the objects undergo violent deceleration and the bus breaks up. The RVs, now glowing with heat, streak toward their targets at an angle of about 23 degrees to the horizontal.

The trajectory shape can be altered at the expense of payload (see Figure 2.2). A lofted trajectory takes longer but reenters faster, and a depressed trajectory can offer unfavorable viewing angles to defensive sensors late in the trajectory.

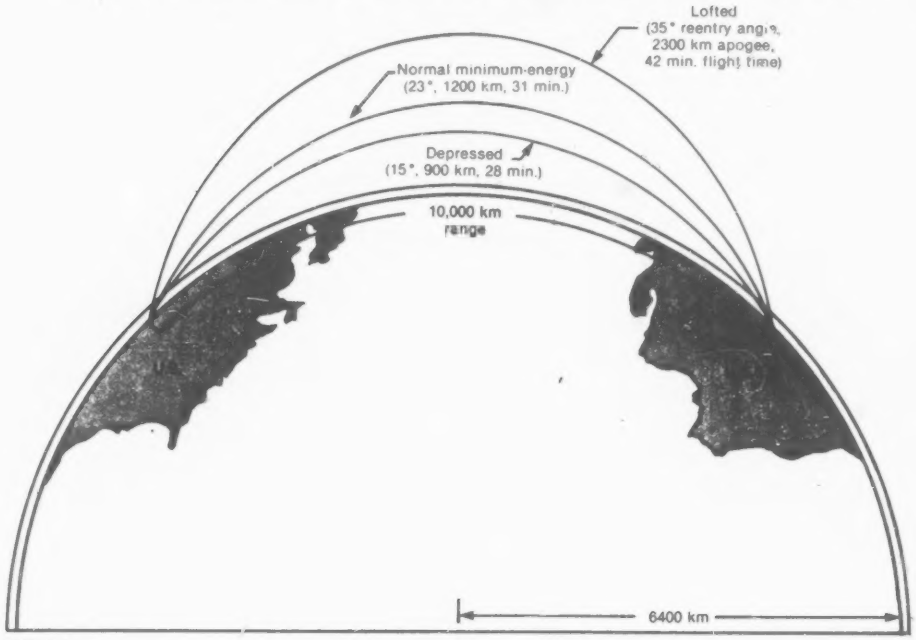
The most important trajectory variations from the point of view of boost phase intercept are variations in boost profile. Boosters like MX were designed with no regard for boost phase BMD, and optimizing their design gave rise to rather long boost times. But boost phase can be shortened--giving less time for boost phase weapons to act—and accomplished within the atmosphere—where certain directed-energy weapons cannot penetrate—with relatively little reduction in payload or increase in missile size. Fast burn is accomplished most easily with solid-fueled rockets. Liquid-fueled boosters like the Soviet SS-18s and SS-19s burn more slowly and burn out at higher altitudes. Thus while MX burns out at 200 km after 3 minutes of boost, the SS-18 burns out at 300-400 km after 5 minutes. The next generation of Soviet ICBMs will reportedly employ solid propellants.

Studies performed for the Defense Department[1] showed that with a 25 percent reduction in payload, a booster about the same size as MX could be built which would burn out in less than 1 minute at only 80 to 90 km, well within the sensible atmosphere. At 90 km the atmosphere is still too dense for extremely accurate RV deployment or for deployment of lightweight RV decoys and other penetration aids aimed at later defensive layers: these functions require an additional 10 to 15 seconds of precision deployment between 90 and 110 km. If the offense needs precision accuracy for some of its ICBMs but fears intercept during these additional few seconds of high-altitude operation, mounting one or two RVs on each of several "microbuses" instead of all the RVs on a single bus affords some protection. Each microbus would contain a simple guidance system only good enough to carry the RVs from upper stage burnout to 110 km. Instead of presenting one target above 90 km, therefore, such a booster would present several targets.

The United States is studying a "Midgetman" missile endorsed by the President's Commission on Strategic Forces (the Scowcroft Commission)

[1] "Short Burn Time ICBM Characteristic and Considerations," Martin Marietta Denver Aerospace, July 20, 1983 (UNCLASSIFIED).

Figure 2.2.—Normal (Minimum-Energy), Lofted, and Depressed ICBM Trajectories, Drawn to Scale



SOURCE: Author

with weight 15 to 25 percent that of MX and carrying one warhead. Midgetman's warhead and bus are combined in one hardened structure. Table 2.1 shows the characteristics of Midgetman variants designed to face a boost-phase intercept system. The fast-burn version burns out at 80 km after 50 secs of boost. With a 10 percent increase in weight, the fast-burn version can carry a substantial payload of penetration aids. A low-flight-profile version is intended to stay within the atmosphere until burnout, protecting it from some types of directed-energy weapon. In the hardened version, one gram of ablative or other shielding material has been applied to each square centimeter of the entire booster body (if the boost-phase intercept system did not begin operation until a minute or so after launch, the first stage might not have to be hardened). These small boosters are all estimated to cost $10 to $15 million per copy, assuming a buy of 1,000 boosters. Costs for the second and subsequent thousand would of course be substantially smaller. These costs are two to three times higher per RV than MX.

The Soviet ICBM arsenal today comprises about 1,400 boosters, more than two-thirds of them MIRVd. Most are slow-burning liquid-fueled boosters. The U.S. arsenal contains about 1,000 faster-burning solid-fueled Minuteman boosters, about half of them MIRVd. Both sides are adding solid boosters to their arsenals in the 1980's.

The geographic distribution of offensive boosters can also be important to space-based boost-phase defenses. The number of satellites required in a defensive constellation usually increases if all opposing ICBM silos are concentrated in one region and decreases if the silos are spread over

Table 2.1.—ICBM Booster Characteristics

	Gross weight (kg)	Length (m)	Width (m)	Type	Booster burnout time (seconds after launch)	Booster burnout altitude (km)	End bussing time (seconds after launch)	End bussing altitude (km)	Comments
SS-18	220,000[a]	35.0	3.0	2-stage liquid	~300	~400	—	—	—
MX Peacekeeper	89,000	21.3	2.3	3-stage solid	180	200	650	1,100	Carries 10 RVs on a single bus
MIRVd fast-burn booster	87,000	22.9	2.1	2-stage solid	50	90	60	110	Deploys several "microbuses" carrying RVs and decoys
Midgetman	19,000	12.1	1.5	2-stage solid	220	340	—	—	Carries one accurate RV
Midgetman fast-burn	20,000	13.8	1.5	2-stage solid	50	80	—	—	Carries one accurate RV
Midgetman fast-burn with midcourse penetration aids	22,000	14.3	1.5	2-stage solid	50	80	—	—	Carries one accurate RV plus decoys
Midgetman with low flight profile	25,000	13.4	1.5	1st stage solid, 2nd liquid	220	100	—	—	Carries one accurate RV
Hardened Midgetman	30,000	15.1	1.5	1st stage solid, 2nd liquid	220	320	—	—	Carries one accurate RV; entire booster covered with 1gm/cm² shielding
Pershing II	7,500	10.5	1.0	2-stage solid	100	—	—	—	—

[a]*Soviet Space Programs 1976-1980* (Committee on Commerce, Science, and Transportation, U.S. Senate, December 1982), Part 1, p. 63.

SOURCE: Except where indicated, "Short Burn Time ICBM Characteristics and Considerations," and accompanying backup, presented to DTST, July 20, 1983, by Martin Marietta Denver Aerospace (UNCLASSIFIED).

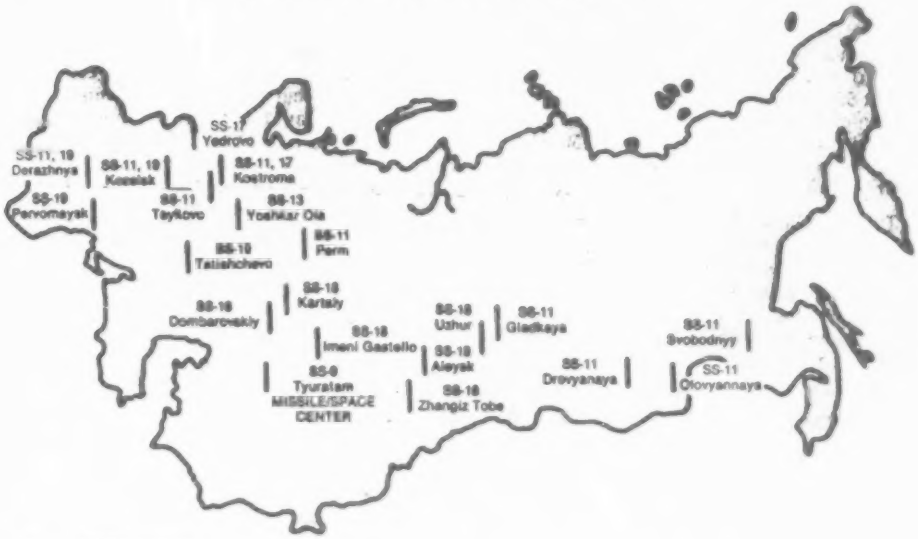
wide land areas. (On the other hand, too much concentration allows defensive satellites to be focused on one region by choosing the orbits judiciously.) Soviet SS-18 ICBMs, their largest MIRVd missiles, are organized into 6 wings of about 50 missiles each, spread out over a large region of the U.S.S.R. U.S. Minuteman missiles are organized into 6 wings of about 150 missiles each. Figures 2.3 and 2.4 show the geographic distributions.

The capabilities of a hypothetical future U.S. BMD should be measured against the *future* and *potential* Soviet ICBM arsenal, not against today's arsenal. The future arsenal will differ due to the natural retirement of old ICBMs and introduction of new ones, and because the Soviets might well react with new and different deployments when they learn of any U.S. plans to deploy defenses. It is impossible to project Soviet deployments far into the future. A reasonable "baseline" estimate for the Soviet ICBM arsenal 15 to 20 years from now might assign them the same number of boosters they have today, but with burn characteristics similar to the U.S. solid-propellant MX. This Background Paper indicates where and how the effectiveness of a hypothetical U.S. defense depends on the nature of the offensive arsenal it faces. In addition to having shorter average burn times, future Soviet ICBMs could be more numerous, deployed less widely geographically, less highly MIRVd, hardened against intercept, and so on.

Figure 2.3.—Present U.S. ICBM Deployment Areas

SOURCE: OTA, *MX Missile Basing*, p. 274.

Figure 2.4—Present U.S.S.R. ICBM Deployment Areas



Type	ICBMs Number
SS-11	550
SS-13	60
SS-17	150
SS-18	308
SS-19	330
	Total 1398

SOURCE: U.S. DOD, *Soviet Military Power*, 2nd ed., p. 14.

Section 3
DIRECTED ENERGY WEAPONS FOR BOOST-PHASE INTERCEPT

This section describes the entire set of "beam weapons" being considered in the United States today for boost-phase ICBM intercept. Though these weapons receive the most attention, the "kill mechanism" that destroys the booster is not necessarily the most important or technically challenging part of an overall defense system. The next section describes other essential elements of a boost-phase defense.

A revisit to this subject several years from now might well find a new family of directed energy concepts receiving attention. But for now the devices described in this section are the basis for assessments of the prospects for efficient boost-phase defense, in the Defense Department and elsewhere (fig. 3.1). Though some of these concepts are new, many have in fact existed in one form or another for more than twenty years.

Figure 3.1

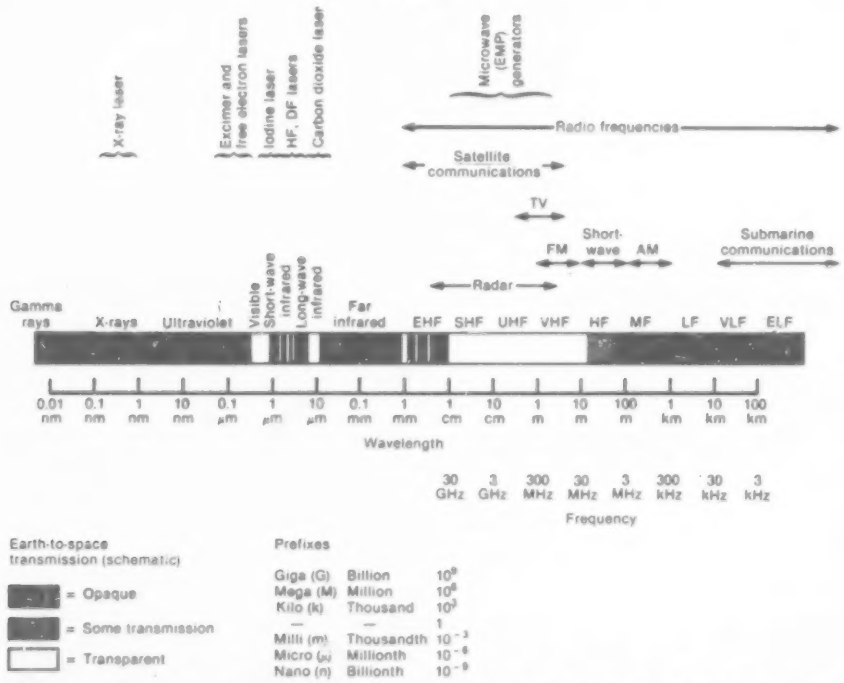


Figure 3.1 The electromagnetic spectrum, showing spectral regions of interest for directed energy BMD. Particle beams and kinetic energy weapons are not shown because their energy does not consist of electromagnetic radiation, but of atomic and macroscopic matter, respectively. Source: Author

For each concept this section attempts to work through, with some concreteness, the design of a hypothetical defensive system based on the concept. The resulting designs are *illustrative only;* no significance should be attached to precise numbers. Precision is simply not possible in the current state of technology and study of these concepts.

In all cases, the "current state of technology" (however this is defined in each case) is far from meeting the needs of truly efficient boost-phase intercept. The systems designed in this section illustrate the level to which technology would have to progress to be "in the ballpark." Much attention fastens on the gulf between the current state of technology and the ballpark requirements. This section does not emphasize such comparisons for several reasons. First, in some cases details of the precise status of U.S. research is classified. Second, and more importantly, quantitative comparisons (e.g., "A millionfold increase in brightness is required to fashion a weapon from today's laboratory device") can mislead unless accompanied by a deeper explanation of the technology; and the same quantitative measures are not appropriate for all technologies. Third, and most importantly, such comparisons imply that learning how to build the right device is tantamount to developing an efficient missile defense, which is far from true: equally crucial are design of a sensible system architecture, cost, survivability, resilience to countermeasures, and the myriad detailed limitations that do not turn up until later in development.

3.1 SPACE-BASED CHEMICAL LASERS: A FIRST EXAMPLE

This concept of directed energy weapon has been the one most frequently discussed in recent years for boost-phase ICBM intercept. For this reason (and not necessarily because it is the most plausible of all the concepts), it will be used to introduce certain features common to all the schemes that follow.

Making and Directing Laser Beams

A molecule stores energy in vibrations of its constituent atoms with respect to one another, in rotation of the molecule, and in the motions of the atomic electrons. The molecule sheds energy in the form of emitted light when it makes transitions from a higher-energy state to a lower-energy state. Lasing takes place when many molecules are in an upper state and few are in a lower state: one downward transition then stimulates others, which in turn stimulate yet more, and a cascade begins. The result is a powerful beam of light.

Energy must be supplied to the molecules to raise most of them to the upper state. This process is called pumping. In the case of the chemical lasers considered in this section, the pumping energy comes from the chemical reaction that makes the lasant molecules: hydrogen and fluorine react to form hydrogen fluoride (HF) molecules in an upper state. The other requirement for lasing—few molecules in the lower state—is satisfied simply by removing the molecules from the reaction chamber after they have made their transitions to the lower state and replacing them with freshly made upper state molecules. The pumping process is not perfect: not all the pumping energy ends up as laser light. The ratio of pumping energy in to laser energy out is called the efficiency of the laser.

Laser light is special in two respects: its frequency is precise, since all the light comes from the same transition in all the molecules; and the light waves from all the molecules emerge with crests and troughs aligned, since the waves are produced cooperatively. These special features make it possible to focus the laser energy with mirrors into narrow beams characterized by small divergence angles (see fig. 3.2). Nonetheless, there is a limit to the divergence angle that even a perfect laser with perfect mirrors can produce. The divergence angle (in radians) can be no smaller than about 1.2 times the wavelength of the light divided by the diameter of the mirror. Thus a laser with 1 micrometer (=1 micron)

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Figure 3.2

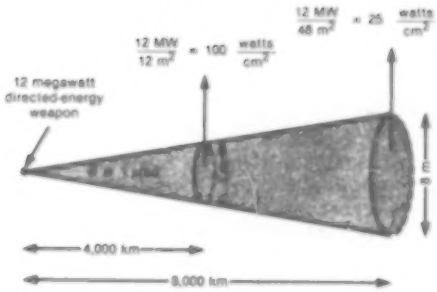


Figure 3.2 Basic power relationships for directed energy weapons. If the directed energy weapon has a divergence angle of 1 microradian, the spot size at a range of 4000 kilometers is 4 meters (12 feet). In this figure, the divergence angle is exaggerated about 1 million times. (For comparison of scale, the Earth's radius is about 6,400 km.) If the directed energy weapon emits 12 megawatts of power, a target within the spot at 4,000 km receives 100 watts on each square centimeter of its surface. (For comparison, 100 watts is the power of a lightbulb, and a typical commercial powerplant produces 1,000 megawatts). Since a watt of power equals one joule of energy per second this weapon would take 10 seconds to apply a kilojoule per square centimeter (1 KJ/cm²) to the target at 4,000 km range. Source: Author

wavelength projected with a 1 meter mirror could have at best a 1.2 microradian divergence angle, making a spot 1.2 meters wide at a range of 1,000 kilometers (refer to fig. 3.2).[1] This perfect performance is called the diffraction limit. Dividing the laser power output by the size of the cone into which it is directed (cone size is measured in units called steradians; a divergence angle of x radians results in a cone of size $\pi x^2/4$ steradians) yields the laser's "brightness," the basic measure of a weapon's lethality.

Destroying Boosters with Lasers

Assuming a high-energy laser with small divergence angle can be formed, stabilized so it does not wave about (jitter), and aimed accurately, what effect will it have on an ICBM booster? No clear answer to this question can be given without more study and testing. Estimates of the hardness achievable with future boosters are probably reliable within a factor of two or three, though estimates of the hardness of current Soviet boosters are probably reliable only to a factor of 10 or so.

Roughly speaking, laser light can damage boosters in two distinct ways. With moderate intensities and relatively long dwell times, the laser simply burns through the missile skin. This first mechanism is the relevant one for the chemical lasers described in this section. The second mechanism requires very high intensities but perhaps only one short pulse: the high intensity causes an explosion on and near the missile skin, and the shock from the explosion injures the booster. This mechanism, called impulse kill, is more complex than thermal kill and is less well understood. It will be discussed in the next section.

Bearing in mind the uncertainties in these estimates, especially the complex interaction of heating with the mechanical strains of boost, the following estimates are probably reliable: A solid-fueled booster can probably absorb without disruption up to about 10 kilojoules per square centimeter (kJ/cm²) on its skin if a modicum of care is taken in the booster's design to eliminate "Achilles' heels." This energy fluence would result from 1 second of illumination at 10 kilowatts per square centimeter (kw/cm²), since one watt equals one joule per second.[2] Applying ablative (heatshield) material to the skin can probably double or triple the lethal fluence required. Applying a mirrored reflective coating to the booster is probably not a good idea, since abrasion during boost could cause it to lose its lustre. Spinning the booster triples its hardness, since a given spot on the side of the booster is then only illuminated about a third of the time.[3] On the other

[1] The spot from a perfect laser with perfect mirrors would actually be brighter at the center than at the edges. The full angle subtended by this spot (the Airy disk from null to null in the diffraction pattern), is 2.4 times the wavelength divided by the mirror diameter, but most of the energy is in the central fourth of this area: hence the use in the text of the multiplier 1.2.

[2] The lethal fluence (in kJ/cm²) must accumulate over a relatively short time, so that the booster wall suffers a high rate of heating. Thus a flux of 30 watts/cm² would deposit 10 kJ/cm² in 330 sec of dwell time, but such a slow rate of heating would probably not damage the booster.

[3] It is possible that uniform heating around the circumference of the booster introduces lethal mechanisms distinct from those that apply to heating a single spot on the side of the booster. In that case, spinning the booster might not lengthen the required dwell time by the full amount dictated by geometry.

hand, currently deployed boosters, especially the large liquid Soviet SS-18s and SS-19s, might be vulnerable to 1 kJ/cm² or even less. These too could be hardened by applying heatshield material.

An Orbiting Chemical Laser Defense System

Consider a space-based BMD system comprised of 20-megawatt HF chemical lasers with 10 meter mirrors. The HF laser wavelength of 2.7 microns is attenuated as it propagates down into the atmosphere, but most of the light gets down to 10 km or so altitude. Deeper penetration is not really needed, since the laser would probably not be ready to attack ICBMs until after they had climbed to this altitude, and in any event clouds could obscure the booster below about 10 km. (Substituting the heavier and more expensive deuterium, an isotope of hydrogen, to make a DF laser at 3.8 micron wavelength would alleviate attenuation, but the longer wavelength would require larger mirrors.)

A perfect 10 meter mirror with a perfect HF laser beam yields 0.32 microradian divergence angle. The spot from the laser would be 1.3 meters (4.0 ft) in diameter at 4 megameters (4,000 kilometers) range. 20 megawatts distributed evenly over this spot would be an energy flux of 1.5 kw/cm². The spot would need to dwell on the target for 6.6 seconds to deposit the nominal lethal fluence of 10 kJ/cm². At 2 megameters (Mm) range, booster destruction would require only a fourth of this time, or 1.7 seconds of illumination. Since light takes about a hundredth of a second to travel 4 megameters and the booster is traveling a few kilometers per second, the booster moves about 50 meters in the time it takes the laser light to reach it. The laser beam must therefore lead the target by this distance.

The next step is to choose orbits for the satellites so that the U.S.S.R.'s ICBM silos are covered at all times and so that there are enough satellites overhead to handle all 1,400 of the present Soviet booster population. Equatorial orbits (fig. 3.3) give no coverage of the northern latitudes where Soviet ICBMs are deployed. Polar orbits give good coverage of northern latitudes but concentrate satellites wastefully at the poles where there are no ICBMs. The optimum constellation consists

Figure 3.3

Figure 3.3 Designing a constellation of directed energy weapon satellites for optimum coverage of Soviet ICBM fields. Equatorial orbits (a) give no coverage of northern latitudes. Polar orbits (b) concentrate coverage at the north pole. Inclined orbits (c) are more economical. Slight additional economies are possible in some cases with further elaboration of the constellation design. Source: Author

of a number of orbital planes inclined about 70° to the equator, each containing several satellites.

The shorter the lethal range of the directed energy weapon, the lower and more numerous the satellites must be. For instance, with a lethal range of 3 Mm, 5 planes containing 8 satellites each, or a total of 40 satellites, are needed to ensure that Soviet boosters exiting Soviet airspace would be within lethal range of one satellite. If the lethal range is increased to 6 Mm, only 3 planes of 5 satellites each are needed. This dependence of constellation size on weapon range is displayed in figure 3.4. (It is possible to adjust these numbers a bit by using slightly elliptical orbits with apogees over the northern hemisphere, adjusting inclinations and phasing, etc.). In the present example, requiring that at least one HF laser be no further than 4 Mm from each Soviet ICBM site at all times (corresponding to no longer than 6.6 seconds dwell time per booster) results in the illustrative constellation of 32 orbital positions shown in figure 3.5.

Since the 1,400 Soviet boosters currently deployed are spread out over most of the Soviet Union, perhaps 3 of the 32 orbital positions would be over or near the Soviet Union at a time, able to make efficient intercepts. That is, only one in 11 deployed U.S. battle stations would participate in a defensive engagement. The ratio of the total number of battle stations on orbit to the number in position to participate in a defensive engagement is called the absentee ratio. The inevitable waste reflected in the absentee ratio—

Figure 3.4

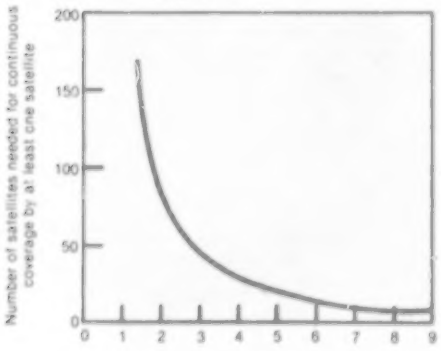
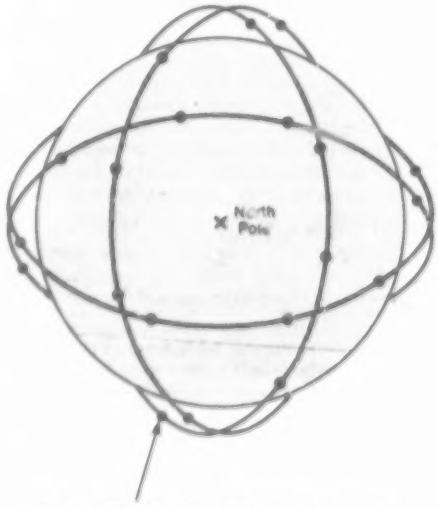

Number of satellites needed for continuous coverage by at least one satellite
200
150
100
50
0
0 1 2 3 4 5 6 7 8 9
Range of directed energy weapon (megameters)

Figure 3.4 The number of satellites needed in a constellation to ensure that at least one satellite is over each Soviet ICBM field at all times depends on the effective range of the directed energy weapon. For every one defensive weapon required overhead a Soviet ICBM field to defend against a rapid Soviet attack, an entire constellation must be maintained on orbit. Since there are many Soviet ICBM fields distributed over much of the Soviet landmass, more than one satellite in each constellation would be in position to participate in a defensive engagement. The ratio of the number of satellites in the constellation to the number over or within range of Soviet ICBM fields is called the absentee ratio. If all Soviet ICBMs were deployed in one relatively small region of the U.S.S.R., the absentee ratio would be the same as the number of satellites in the constellation. Source: Author

Figure 3.5



0 = Cluster of 5 chemical laser battle stations
Total of 32 × 5 = 160 battle stations

Figure 3.5 Constellation of hypothetical directed energy weapon satellites with 4,000 km range. The orbits are circular with 1000 km altitude. Each of the four orbital planes consists of eight positions spaced 45° apart around the circle. In the example given in the text, five chemical laser battle stations are clustered at each point shown in this figure, for a total of 32 x 5 = 160 battle stations. Source: Author

usually on the order of 10—offsets an oft-cited theoretical advantage of boost-phase intercept, namely, that intercepting one booster saves buying 10 interceptors for the booster's 10 RVs. On the other hand, coverage of the U.S.S.R.'s ICBM fields automatically gives good coverage of essentially all submarine deployment areas. Obviously the absentee ratio would be 32—the full constellation size—and not 32/3 = 10.7 if Soviet ICBM silos were not spread out so widely over Soviet territory but were deployed over a third or less of the Soviet landmass, so that only one of the 32 U.S. satellites was within range.

Three of the earlier described laser satellites in position over the Soviet ICBM fields are not enough to intercept 1,400 boosters if all or most of the boosters are launched simultaneously. Each satellite can only handle a few boosters because it must dwell for a time on each one. The time a chemical laser must devote to each booster depends on the satellite's position at the moment of attack—6.6 seconds for 4 Mm range, 1.7 seconds for 2 Mm range, etc. Taking 2 Mm as an average range for the 32-satellite constellation (hoping the Soviets do not choose a moment when most of the U.S. satellites are farther than 2 Mm from the ICBM flyout corridors to launch all their boosters simultaneously), a laser must devote an average of 1.7 seconds to each booster.

If the boosters in the future Soviet arsenal resemble the U.S. MX, and the defense waits 30 seconds or so to confirm warning and to wait for the boosters to climb to an altitude where the HF laser can reach, each booster is accessible for 150 seconds of its 180 second burn time. Each laser can therefore handle no more than 90 boosters, even with instant slewing of the beam from target to target. If 1,400 Soviet boosters were launched simultaneously, (1,400)/(90) ≅ 15 lasers would be needed in position, for a worldwide total (multiplying by the absentee ratio) of (10.7) × (15) = 160 satellites.

If the Soviets doubled their arsenal to 2,800 boosters, the United States would need to deploy another 160 satellites, possibly an uncomfortable cost trade for the United States.

What is worse, if the Soviets deployed 1,400 missiles in a *single region* of the U.S.S.R. (at a U.S.-estimated cost of $21 billion for Midgetman-like ICBMs; see section 2 above), the US would have to build, launch, and maintain on orbit an additional (32) × (1400)/(90) ≅ 500 lasers plus their fuel and support equipment.

If Soviet boosters were covered with shielding material and spun during flight to achieve an effective hardness of, say, 60 kJ/cm², a laser would have to devote 10 seconds to each booster at 2 Mm range, requiring a sixfold increase in the number of satellites, to 960. Alternatively, the average range of each engagement could be reduced to keep the dwell time at 1.7 seconds, with corresponding increase in constellation density (fig. 3.4). Either way, the number of U.S. satellites would grow to nearly the number of Soviet boosters intercepted.

Table 3.1.—Variation of the Number of Chemical Laser Battle Stations Needed to Handle a Simultaneous Launch of Soviet ICBMs, Depending on Characteristics of the Soviet Arsenal and the U.S. Laser Defense

Departure from baseline	Number of Soviet boosters	Booster characteristics	Geographic distribution	Hardness (kJ/cm²)	Laser power (MW) and aperture diameter (m)	Approximate number of battle stations needed
Baseline	1,400	MX-like	Current Soviet	10	20/10	160
Booster number	2,800	MX-like	Current Soviet	10	20/10	320
Deployment geography	1,400	MX-like	One region	10	20/10	500
Booster hardness	1,400	MX-like	Current Soviet	60	20/10	960
Laser brightness	1,400	MX-like	Current Soviet	10	80/50 (100 times brighter)	20-30
Booster burn time	1,400	Fast-burn	Current Soviet	10	20/10	800-1,600
Booster burn time	1,400	SS-18-like	Current Soviet	10	20/10	90

SOURCE: Author.

If the United States developed a battle station 100 times brighter (using, say, a 80 MW laser with an effective mirror diameter of 50 meters), a few lasers overhead (20 to 30 total worldwide) could easily handle an attack of 1400 boosters hardened to 10 kJ/cm². If the boosters were hardened to 60 kJ/cm², over 100 such lasers would be needed.

Deployment by the Soviets of 1400 fast-burn boosters would give the U.S. lasers just 20 to 40 seconds, rather than 200 seconds, to destroy all the boosters. The U.S. constellation would consequently need to grow by a factor 5 to 10, to 800 to 1600 satellites!

Table 3.1 summarizes how the size of the defensive deployment varies with the parameters assumed.

Requirements for a Chemical Laser Defense

Figure 3.6 displays the performance of various hypothetical HF lasers. Keeping the size of the battle station constellation down to a hundred rather than several hundred satellites means lethal ranges of at least 4 Mm with illumination times less than about 1 second, assuming the defense must be capable of intercepting 1,000 to 2,000 Soviet boosters with launches timed to keep the boosters as far from the U.S. lasers as possible. Further assuming Soviet booster hardening to at least 10 kJ/cm² results in a requirement for chemical lasers considerably brighter than the 20 MW, 10-meter laser described above. A hundredfold increase in brightness would be achieved by a laser with power 80 MW and effective mirror diameter 50 meters.

Such a laser would be about 10 million times brighter than the carbon dioxide laser on the Air Force's Airborne Laser Laboratory. The current Alpha laser program of the Defense Advanced Research Projects Agency (DARPA) aims at a construction of an HF laser of just a few megawatts and built only for ground operation. Nonetheless, there is no fundamental technical reason why extremely bright chemical lasers cannot be built. In theory, several lasers can be operated together so that the brightness of the resulting beam increases with the square of the number

Figure 3.6

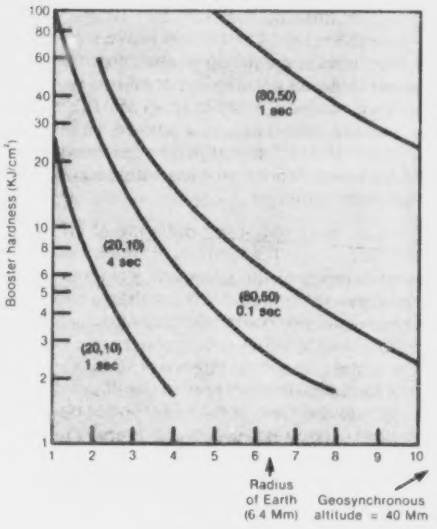


Figure 3.6 Lethal range versus booster hardness for HF chemical lasers of various sizes and dwell times. The labels on the curves have the format (laser power in megawatts, mirror diameter in meters) followed by the amount of time the laser devotes to destroying each booster. Source: Author

of lasers: 10 lasers combined in this way would produce a beam 100 times brighter than each individual laser. The trick is to arrange for the troughs and crests of the light waves from all the lasers to coincide. This theoretical prospect is unlikely to be realized with HF lasers, since their light is actually emitted at several wavelengths and with shifting patterns of crests and troughs.

To yield diffraction-limited divergence, the mirror surface must be machined to within a fraction of a wavelength of its ideal design shape over its entire surface. Since the mirror is over a million wavelengths across, avoiding small figure errors is a severe requirement. A number of small mirrors can obviously combine to produce one large optical surface if their positions are all aligned to within a fraction of a wavelength. The

mirrors must maintain perfect surface shape in the face of heating from the laser beam, vibration from the chemical reaction powering the laser, and vibrations set up in the mirror as it is slewed. Substantial hardening of mirrors to radiation from nuclear bursts in space and to the x-ray laser (described below) would be a challenging task. The 2.5-meter diameter mirror on NASA's Space Telescope was produced without these constraints.

An extremely optimistic outcome of HF laser technology—near the theoretical limit for converting the energy of the chemical reactants to laser energy—would require more than a kilogram of chemicals on board the satellite for every megajoule radiated. A spot diameter of 2 meters at the target and a lethal fluence of 10 kJ/cm² over this area results in an energy expenditure of 300 MJ per booster. Destroying 1,000 Soviet boosters therefore requires, reckoning very crudely, 300,000 kg of chemicals in position over the Soviet ICBM field, or perhaps 10 million kg on orbit worldwide. The space shuttle can carry a payload of about 15,000 kg to the orbits where the satellite battle stations would be deployed. About 670 shuttle loads would therefore be needed for chemicals, with perhaps another half as many for the spacecraft structures, the lasers and mirrors, construction and deployment equipment, and sensors. 1,000 shuttle missions for every 1,000 Soviet boosters (perhaps Midgetmen) deployed in reaction to the U.S. defense is an impractical competition for the United States. Use of HF chemical lasers for BMD therefore requires remarkably cheap heavy-lift space launch capability in the United States.

The remaining components of the chemical laser defense system—sensors, aiming and pointing technology, and communications— are for the most part generic to all directed energy weapons and are discussed in section 4. Section 5 presents countermeasures the Soviets might take to offset or nullify a chemical laser defense.

3.2 GROUND-BASED LASERS WITH SPACE-BASED MIRRORS

A slight variant of the previous concept puts the laser on the ground and mirrors in space, reflecting the light back down toward Earth to attack ascending boosters. This scheme avoids placing the laser and its power supply in space, though mirrors, aiming equipment, and sensors remain. The excimer and free-electron lasers considered for this scheme are in fact likely to be rather cumbersome, so ground basing them might be the only practical way to use them for BMD. The lasers would emit at visible or ultraviolet wavelengths about ten times shorter than the near-infrared wavelengths of the HF and DF chemical lasers in the space-based concept. Shorter wavelengths permit use of smaller (though more finely machined) mirrors. The high power available with ground basing suggests at least the possibility of impulse rather than thermal kill of boosters.

The term excimer is a contraction of "excited dimer." A dimer is a molecule consisting of two atoms. The dimers considered for these lasers contain an atom of noble gas and a halogen atom, making dimers like xenon fluoride (XeF), xenon chloride (XeCl), and krypton fluoride (KrF). The laser light comes from dimers in an excited upper state decaying to a lower state, just like in the HF laser. Excimer lasers tend to emit light in pulses rather than in a continuous wave. The population of upper-state molecules is provided by pumping with electric discharges in a rather complicated process. The population of lower-state molecules remains small because the lower-state dimer is unstable and quickly breaks up into its two constituent atoms. The pumping process for excimer lasers is inefficient, so only a small fraction of the energy put into the laser in the electric discharge emerges as laser light. Powerful excimer lasers would therefore be large and would need to vent large amounts of wasted energy; these characteristics make them unsuitable for space basing. Development of excimer lasers is at an early stage, and no excimer lasers exist with anything remotely approaching the characteristics needed for this boost phase intercept concept.

Figure 3.7

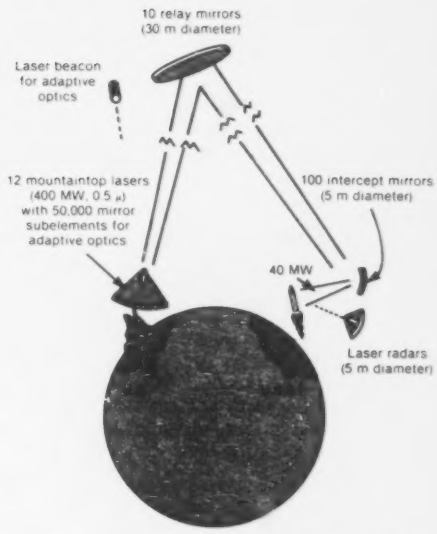


Figure 3.7 Illustrative configuration of ground-based excimer or free-electron laser and space-based mirrors for thermal kill of Soviet ICBM boosters. Source: Author

Power outputs achieved in the laboratory are still several orders of magnitude less than the average power needed for thermal kill, and the energy achieved in a single pulse is much smaller than the single-pulse energies needed for impulse kill.

The working of a free-electron laser (FEL) is more complicated.[4] As the name suggests, the light-emitter (lasant) is free electrons emitted from a particle accelerator. Pumping therefore originates in the electrical source powering the accelerator. The free electrons from the accelerator are directed into a tube called the wiggler that has magnets positioned along its length. The magnets cause the electrons to wiggle back and forth as they transit the tube. As they wiggle, the electrons emit some of their energy as light. The presence of light from one electron causes others to emit in the usual cooperative manner of a laser, and a cascade begins. By adjusting the positions of the magnets and the energy of the electrons, the wavelength of the light can be tuned to any value desired. The only advantage of the FEL over excimer lasers is the high efficiency that can (theoretically) be obtained with the former. It has been suggested that it might even be possible to position FELs in space like HF chemical lasers. FEL operation at visible wavelengths is in its infancy, and the experimental devices used are many millions of times less powerful than those required in this BMD.

The BMD scheme calls for a large ground based excimer or free electron laser, relay mirrors at high altitude to carry the laser beam around the curve of the Earth, and intercept mirrors to focus the beams on individual boosters (fig. 3.7). The characteristics of a nominal system for thermal booster kill are easily ascertained. Suppose first that there are enough intercept mirrors so that the average range from mirror to booster is 4 Mm, and suppose the Soviet boosters are destroyed with 10 kJ/cm² deposited on a spot as small as several centimeters wide. Assume the excimer or free electron laser operates at about 0.5 microns, in the visible band. Then a 5 m intercept mirror will produce a spot 50 cm wide at 4 Mm range. If a half second of the main laser beam is devoted to each booster, then the required 10 kJ/cm² will be accumulated if the power reflected from each intercept mirror is 40 MW.

Only about a tenth of the power emitted by the ground based laser in the United States would be focused on the booster over the U.S.S.R. The remainder would be lost in transit through the atmosphere and in reflection from the two mirrors. Thus a 400 MW laser is required.

Passage through the atmosphere poses a number of problems for the primary laser beam. The most important source of interference is turbulence in the air, causing different parts of the laser beam to pass through different optical environments when exiting the atmosphere. Each part of the beam suffers a slightly different disruption, and the beam that emerges does not have the

[4]See Charles A. Brau, "Free Electron Laser: A Review," *Laser Focus*, March 1981; *Physics Today*, December 1983, p.17.

orderly arrangement of crests and troughs needed for diffraction-limited focusing from the intercept mirror. Without compensation for atmospheric turbulence, the ground-based laser scheme is completely impractical. Fortunately, the pattern of turbulence within the laser beam, though constantly changing, remains the same for periods of a few milliseconds. Since it takes only 0.1 millisecond for light to make a round trip through the atmosphere, the effect of turbulence on the laser beam can be compensated for with the following technique, called adaptive optics: A low-power laser beacon is positioned near the relay mirror. A sensor on the ground observes the distortion of the beacon beam as it passes through the atmosphere. The beam from the ground-based laser is then predistorted in just such a way that its passage through the same column of air transited by the beacon beam re-forms it into an undistorted beam.

Figure 3.7 shows the many components required by the ground-based laser concept. Since each Soviet booster requires 0.5 sec of beam at some time during its 200 sec. boost phase, four beams would be needed to handle 1,400 Soviet boosters launched simultaneously (assuming no retargeting delays). The lasers should be deployed on mountain tops to make atmospheric effects manageable, and enough should be deployed that at least four sites are always clear of cloud cover. The mirror on the ground would need to be tens of meters across and divided into tens of thousands of individually adjustable segments for predistortion of the wavefront. Each relay mirror would need to be accompanied by a beacon. Four large interception mirrors would be needed within 4 Mm of each Soviet ICBM flyout corridor, giving a worldwide constellation of a hundred or so.

The small laser wavelength means that all mirrors must be more finely machined than the mirrors for the chemical laser and can tolerate smaller vibrations and stresses due to heating from the laser beam. The small wavelength also results in a spot 10 times smaller at the target than the spot from a chemical laser beam at the same range. This small spot requires pointing accuracy ten times finer. Perhaps most important of all, the plume from the booster motor is too large to serve as target for such a narrow beam. Some way of seeing the actual missile body against the background of the plume is needed for the short-wavelength laser schemes (and for some configurations of chemical lasers). One answer to this problem, described in section 4 below, is to position near each intercept mirror a low-power laser and a telescope (a laser radar or ladar): the laser illuminates the booster and the telescope observes the reflected laser light, directing the pointing of the intercept mirror. The ladar telescope must have a mirror as large as the intercept mirror, since it must be able to "see" a spot as small as that made by the beam.

A single immense laser pulse that deposits 10 kJ/cm² in a very short time—millionths of a second rather than a second— might cause impulse kill rather than thermal kill. In impulse kill, the laser pulse vaporizes a small layer of the booster skin and surrounding air. The superheated gases then expand explosively, sending an impulsive shockwave into the booster. A strong enough shockwave might cause the booster skin to tear. The advantage of this kill mechanism is that it would be very difficult to protect boosters from it. The disadvantages are that impulse kill requires prodigious laser pulses and mirrors that can withstand them, and that the mechanism is poorly understood and depends on myriad factors like the altitude of the booster at the moment it is attacked.

3.3 NUCLEAR BOMB-PUMPED X-RAY LASERS: ORBITAL AND POP-UP SYSTEMS

The U.S. Government has revealed efforts at its weapon laboratories to use the energy of a nuclear weapon to power a directed beam of x-rays. Such devices are said to constitute a "third generation" of nuclear weapons, the first two generations being the atomic (fission) and hydrogen

(fusion) bombs. Each succeeding generation represented a thousandfold increase in destructive energy, from a ton of high explosive to a kiloton fission weapon to a megaton fusion weapon. The third generation weapon uses the same amount of energy as the fusion weapon, but directs much of that energy toward the target rather than allowing it to escape in all directions. At the target, therefore, the energy received is much greater than the energy that would be received from a hydrogen bomb at the same range.

X rays lie just beyond ultraviolet light on the electromagnetic spectrum and have wavelengths about a thousand times smaller than visible light (see fig. 3.1). Compared to the infrared, visible, and ultraviolet lasers in the previous sections, the x-ray laser produces much more energy from its bomb pump, but the energy is spread out over a larger cone. The lethal ranges for boosters turn out to be roughly comparable for all these types of directed-energy device. Obviously the x-ray laser delivers all its energy in one pulse, so there is no question of dwell time on the target. Very short-wavelength x-rays penetrate some distance into matter (witness dental and medical x-rays), but the longer-wavelength x-rays produced by a laser device do not penetrate very far into matter or into the atmosphere.

Orbiting and ground-based "pop-up" systems have been proposed as ways to make use of the x-ray laser for boost phase BMD. Both of these schemes have attractive features but also serious drawbacks. It could well be that the x-ray laser device, if a powerful one can eventually be built, will be more useful in other strategic roles than boost-phase BMD.

X-Ray Lasers

Little has been revealed about the characteristics of the bomb-pumped x-ray laser being studied by the United States (the so-called Excalibur device), but some general information can be deduced from the laws of physics and, to a lesser extent, from the scientific literature here and in the Soviet Union.[5]

[5]F. V. Bunkin, V. I. Derzhiev, and S. I. Yakovlenko, *Soviet Journal of Quantum Electronics 11* (8), August 1981, p. 981. R. C. Elton, R. H. Dixon, and J. F. Seely, *Physics of Quantum Electronics 6* (1978), p. 243. Michael A. Duguay, *Ibid.*, p. 557. G. Chapline and L. Wood, *Physics Today*, June 1975, p. 40.

Figure 3.8

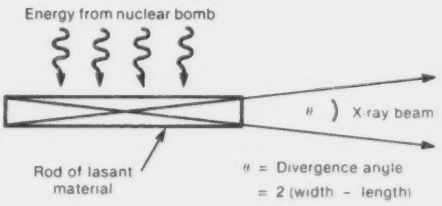


Figure 3.8 In an x-ray laser, a rod of lasant material is pumped to upper energy states by a nuclear bomb. Those cascades of downward transitions that travel lengthwise build up more energy than sideways-going cascades. As a result, most of the energy emerges from the ends of the rod into a cone with divergence angle equal to twice the rod width divided by its length. Source: Author

The pumping source for the x-ray laser is a nuclear bomb. The radiant heat of the bomb raises electrons to upper energy levels in atoms of lasant material positioned near the detonation (the chemical nature of the lasant material has not been revealed). As the electrons fall back again to lower levels, it can happen that for a moment many atoms are in a given upper level and few in a lower level; this is the necessary condition for lasing from the upper level to the lower level. The wavelength of the emitted x-ray is determined by the energy levels involved. The wavelength of the laser under study in the United States is classified. We will use a round number of 1 nm.

Since x-rays are not back-reflected by any kind of mirror, there is no way to direct the x-rays into a beam with optics like the visible and infrared lasers. Nonetheless, some direction can be given to the laser energy by forming the lasant material into a long rod. Recall that a laser beam builds up when light from one lasant atom stimulates the upper-to-lower-level transition in another atom, which stimulates a third, and so on. The result is a cascade of light heading in same direction as the light from the original atom. The light pulse gets stronger and stronger as it traverses the lasant medium stimulating more and more transitions. In a long rod of lasant material, cascades that get started heading lengthwise down the rod are highly amplified by the time they leave the rod, whereas sideways-going cascades remain small. The result is that most of the laser energy

emerges as a beam aligned along the rod axis (fig. 3.8).

The projected capabilities of the x-ray lasers being studied in the U.S. are classified; but it is fairly easy to determine the upper limit to how powerful such a laser could possibly be. Whether R&D will succeed in making such a perfect laser cannot be said. But it will become clear that something very close to the perfect laser is required for boost phase intercept, though a less successful development would still yield a potent antisatellite weapon.

A 1-megaton nuclear weapon releases about 4 billion megajoules of energy. By surrounding the bomb with lasant rods, most of this energy can be harnessed to pump the laser. Since the pumping mechanism for the x-ray laser is rather disorganized and wasteful, like the pumping mechanism for excimer lasers, at most a few percent of the bomb energy can be expected to end up in the laser beam.

The resulting 100 million megajoules or less of laser energy emerges from the rods into cones with relatively large divergence angle. It is easy to see why this divergence angle is much larger than the divergence angle obtained with the mirror-directed lasers treated in the previous section. The divergence angle is determined by the ratio of the width of the rod to its length, as in figure 3.8. A practical length for a rod is no more than about 5 meters. Making the rod thinner decreases the divergence angle, but beyond a certain point no further narrowing of the beam cone is possible. The limit arises from diffraction, just as with the infrared and visible lasers: the divergence angle of light emitted from an aperture (mirror, rod tip, or anywhere else) cannot be less than about 1.2 times the wavelength of the light divided by the diameter of the aperture. A very narrow rod therefore actually aggravates diffraction and produces a wide cone. Making the rod thinner results in no further narrowing of the beam when (1.2) (wavelength)/(rod width) $\cong$ (2) (rod width)/(rod length). For an x-ray wavelength of 1 nm and a rod length of 5 meters, this equation yields an optimum rod width of 0.06 mm and a minimum achievable (diffraction-limited) divergence angle of 20 microradians.

A 1-megaton bomb-pumped x-ray laser can therefore deposit no more than about 100 million megajoules into a cone no narrower than about 20 microradians. The x-ray pulse from detonating such a perfect laser would deposit about 300 kJ/cm^2 over a spot 200 meters wide at 10 Mm range.

Interaction of X-rays with Matter

X-rays of 1 nm wavelength do not penetrate very far into matter: all the energy from such a laser would be absorbed in the first fraction of a millimeter of the aluminum skin of a missile. This paper-thin layer would explode, sending a shockwave through the missile. Thus the x-ray laser works by impluse kill.

Another consequence of the opacity of matter to x-rays is that the laser beam would not propagate very far into the atmosphere. The altitude to which the beam would penetrate depends on the precise wavelength, which is classified. For the nominal 1 nm wavelength described above, boosters below about 100 km would be quite safe from attack. If the wavelength were much shorter, the x-rays would penetrate lower, reaching perhaps 60 km altitude or so. In what follows, it will be assumed that boosters are safe from x-ray laser attack below about 80 km.

One last consequence of the physics of x-ray interaction with matter is noteworthy. When an atom of matter absorbs an x-ray, it emits an electron. As x-rays are absorbed, it becomes harder and harder to remove successive electrons. Finally further x-rays cannot remove further electrons, and the matter becomes transparent. This phenomenon, called bleaching, means that a strong x-ray laser beam can force its way through a column of air by bleaching the column, but a weak laser beam is completely absorbed. An x-ray laser in the atmosphere might therefore be able to attack an object in space because the beam is intense enough in the vicinity of the laser to bleach the air, whereas an x-ray laser in space could not attack objects within the atmosphere. This fact bodes ill for defensive space-based x-ray lasers attacked by similar lasers (or

even weaker ones) launched from the ground by the offense.

As with visible and infrared lasers, the lethality of an x-ray laser is subject to large uncertainties. The proper order of magnitude for the amount of x-ray energy per square centimeter that needs to be deposited on the side of a booster to damage it can be estimated fairly easily. But the actual hardness of a booster would depend on many design details in a way that is not fully understood at this time. A simple calculation[6] indicates that 20 kJ/cm² is a reasonable number to take for the hardness of a booster. This is about the same as for impulse kill by visible laser. An RV would be harder, and a satellite softer.

Orbital Defense Concept

The "perfect" x-ray laser whose characteristics were deduced above would be capable of intercepting a booster from geosynchronous orbit 40,000 km above the Earth. One laser would be needed for each Soviet booster. At lower altitudes, the rods surrounding the bomb could be gathered into several bundles and each bundle aimed at a different booster. At these lower altitudes, though, the absentee problem means that roughly one x-ray laser device would still need to be placed in orbit for each Soviet booster. Though the x-ray lasers are small and light compared to a chemical laser, the cost tradeoff involved in launching a new laser every time the Soviets deploy a new ICBM is obviously not a tolerable one for the United States.

The x-ray laser can attack the boosters after they have left the protective atmosphere but before burnout. Simultaneous launch of all Soviet boosters is not a problem for x-ray lasers in the way it is a problem for chemical lasers that must dwell on each target before passing on to the next. Fast-burn boosters are likewise not a crippling problem for an orbiting x-ray laser system *unless* they burn out before they leave the atmosphere. Other countermeasures, most notably the vulnerability of U.S. orbital x-ray lasers to Soviet x-ray lasers, are treated in section 5.

Pop-Up Defense Concept

The pop-up concept represents an attempt to avoid the one-laser-per-booster cost exchange and the vulnerability associated with basing the lasers in space (though crucial sensors remain space-based even in the pop-up scheme). The small size and light weight of the bomb-pumped lasers makes it possible to consider basing them on the ground and launching them into space upon warning of Soviet booster launch.

Figure 3.9 shows why basing the pop-up lasers in the United States is not practical. During the 200 seconds or so of burn time of a Soviet MX-

Figure 3.9

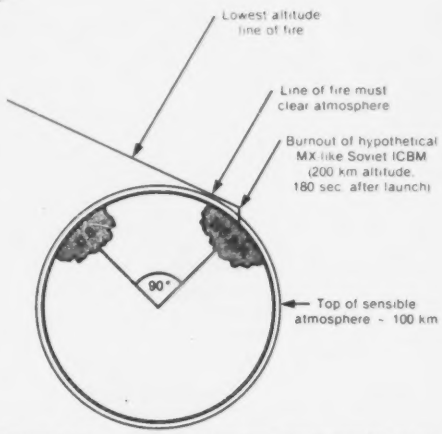

Lowest altitude line of fire
Line of fire must clear atmosphere
Burnout of hypothetical MX-like Soviet ICBM (200 km altitude, 180 sec. after launch)
90°
Top of sensible atmosphere ~ 100 km

Figure 3.9 X-ray lasers launched from the United States on warning of Soviet ICBM launch would have to climb at least as high as the line of fire shown in the figure within three minutes to intercept an MX-like Soviet ICBM. Such a huge fast-acceleration defensive booster would be many times larger than the Saturn V that took astronauts to the moon.
Source: Author

[6]A mallet or soft hammer blow applies an impulse per unit area of about 10 ktaps (0.5 kg hammer head, 5 m/sec striking velocity, 3 cm radius contact area; 1 tap = 1 dyne-sec/cm²). To apply an impulse of this strength to the entire side of an ICBM booster requires a fluence F, whose order of magnitude can be estimated as follows: The cold mass absorption length (a) for 1nm x-rays is about 0.5 milligrams/cm². If all the energy absorbed by the paper-thin absorbing layer were converted to kinetic energy, the boil-off velocity would be $(F/a)^{1/2}$, meaning an impulse per unit area of order $(Fa)^{1/2}$. 10 ktaps is therefore produced if F = 20 kJ/cm².

In reality, not all the deposited energy couples to the booster in this way. A more careful calculation of this lessened coupling has been performed by Hans Bethe (private communication).

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like ICBM, the U.S.-based pop-up lasers would have to climb high enough to see the Soviet boosters over the Earth's horizon and have a line-of-fire unobstructed by the absorbing atmosphere. Climbing so high so fast requires a booster for the x-ray lasers that is many thousands of times larger than the Saturn V rocket that carried U.S. astronauts to the Moon.

If the British Government allowed the U.S. Government to base x-ray lasers in the United Kingdom, the lasers would be separated from Soviet ICBM silos by only 45 degrees of arc rather than 90 degrees as with U.S. basing. Even so, popping up to attack an MX-like Soviet booster would require an enormous fast-burn booster for the x-ray laser and would put it into position to attack the Soviet booster only seconds before burnout. If the Soviets depressed the trajectory or shortened the burn time of the offensive booster very slightly, or if the United States suffered any delay whatsoever in launching the defensive boosters after Soviet launch (instantaneous warning), this hypothetical U.K.-based system would be useless.

A final possibility would be launch of defensive lasers from submarines stationed immediately off Soviet coasts—in the Kara Sea or Sea of Okhotsk, separated from Soviet silos by about 30 degrees of arc—on SLBM-sized fast-burn boosters. With instantaneous warning, a sea-based laser might be able to climb to firing position a few seconds before burnout of a Soviet MX-like ICBM and would enjoy almost an entire minute of visibility to a slow-burning, high-burnout-altitude booster like the SS-18. Because of the short range, each bomb-pumped laser of the perfect design described above could attack many (over 100) boosters using many individual lasing rods. Such efficiency could well be essential, since a submarine cannot launch all its missiles simultaneously and might only be able to fire one defensive missile in the required few seconds. If the MX-like Soviet boosters were flown on slightly depressed trajections, if warning were not communicated to the submerged submarine promptly, if a human decision to launch defensive missiles were required, or if the Soviets deployed boosters that burned faster than MX, the sub-launched system would be nullified. Last, submarine patrol very near to Soviet shores suggests the possibility of attacking the submarine with shore-based nuclear missiles as soon as its position has been revealed by the first defensive launch. Other countermeasures are discussed in Section 5.

3.4 SPACE-BASED PARTICLE BEAMS

Beams of atomic particles would deposit their energy within the first few centimeters of the target rather than at the very surface as with lasers. The effects of irradiation with the particle beam could be rather complex and subtle and would probably depend on design details of the attacking Soviet booster. The result is uncertainty of several factors of ten in the effective hardness of an ICBM booster to beam weapon irradiation.

Only charged particles can be accelerated to form high-energy beams, but a charged beam would bend uncontrollably in the Earth's magnetic field. (There is one theoretical exception to this statement, described below.) For this reason neutral particle beams, consisting of atomic hydrogen (one electron bound to one proton), deuterium (one electron, one proton, one neutron), tritium (electron, proton, two neutrons) or other neutral atoms are considered. To produce a neutral hydrogen (H°) beam, negative hydrogen atoms ($H-$) with an extra electron are accelerated; the extra electron is removed as the beam emerges from the accelerator.

Two features of neutral particles beams dominate their promise as boost phase intercept weapons (leaving aside entirely the issue of countermeasures). The first is the uncertain lethality of the beam. The second is the fact that the beam

cannot propagate stably through even the thinnest atmosphere and must wait for an attacking booster to reach very high altitude.

Generating Neutral Particle Beams

The accelerator that accelerates the negative hydrogen ion is characterized by its current in amperes, measuring the number of hydrogen ions per second emerging from the accelerator; and by the energy of each accelerated ion in electron volts (eV; 1 eV = 1 watt per ampere). Multiplying the current by the energy gives the power of the beam, so that a l-amp beam of 100 MeV particles carries 100 MW of power. Ground-based high-current accelerators and ground-based high-energy accelerators have been built and are operated daily in laboratories. One of the challenges for neutral particle beams as weapons is that they require *both* high current *and* high energy. Another challenge is to provide multi-megawatt power sources and accelerators in a size and weight suitable for space basing.

Magnets focus and steer the beam as it emerges from the accelerator. The last step is to neutralize the beam by passing it through a thin gas where the extra electron is stripped off in glancing collisions with the gas molecules, forming H° from H^{-}. The divergence angle of the beam is determined by three factors. First, the acceleration process can give the ions a slight transverse motion as well as propelling them forward. Second, the focusing magnets bend low-energy ions more than high-energy ions, so slight differences in energy among the accelerated ions lead to divergence (unless compensated by more complicated bending systems). Third, the glancing collisions that strip off the extra electron give the H atom a sideways motion. This last source of divergence is unavoidable and, by the Heisenberg uncertainty principle, cannot be controlled or compensated. It sets a lower limit on the divergence angle achievable with this method of producing neutral particle beams. Table 3.2 shows the divergence angle resulting from this third source, assuming perfect control of the first two sources. The divergence cone from a neutral particle beam is therefore about 10 times larger than the beam from the chemical laser of section 3.1 and 10 times smaller than from the x-ray laser of section 3.3.

A 100 MeV, 0.5 amp neutral tritium (T°) beam thus directs 50 MW of power into a cone of divergence angle 2 microradians, producing a spot 10 meters across at 5 Mm range. A target within this spot receives only 65 watts/cm², requiring 1.5 seconds of dwell time to deposit only 100 J/cm².

Booster Vulnerability to Particle Beams

As soon as the neutral particle beam hits the target, the remaining electron is stripped off, leaving the energetic proton (or deuteron or triton) penetrating deeply into the target. The proton scatters electrons in its path, giving up a small amount of its energy to the electron in each collision. When it has given up all its energy, it stops. For most of its path, it deposits energy uniformly. Thus if a 100 MeV T° beam penetrates 4 cm into the propellant in a missile, it deposits about 25 MeV along each cm. Protons penetrate more deeply than tritons of the same energy, and all particles penetrate more deeply as they are given more energy (table 3.3).

Table 3.2.—Neutral Particle Beam Divergence Angle

	H°	T°
100 MeV	3.6 microradians	2.0
500 MeV	1.4	1.0

Divergence angle introduced by stripping electrons from a beam of negative hydrogen or tritium ions to produce a neutral beam. This source of divergence is an unavoidable consequence of the Heisenberg uncertainty principle applied to the sudden stripping of the electron. If the satellite-based accelerator of the negative ions were absolutely perfect, this amount of divergence would remain.

SOURCE: Author

Table 3.3.—Penetration Range of Neutral Particle Beams Into Matter (in centimeters)

	H°		T°	
	100 MeV	250 MeV	100 MeV	250 MeV
Solid propellant or high explosive (density 1.0 gm/cm³)	9.5	46.6	4.2	20.2
Aluminum	3.5	17.2	1.6	7.6
Lead	0.8	3.9	0.4	1.7

SOURCE: Author

Figure 3.10

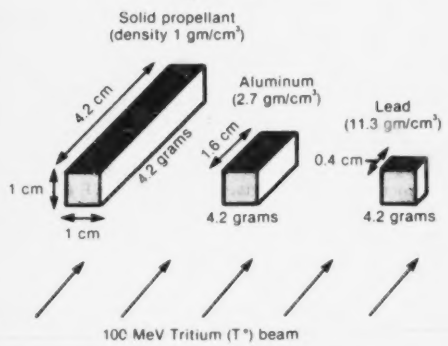


Figure 3.10 A neutral particle beam penetrates farther into an aluminum target than into a lead target but deposits the same energy per gram. Though the energy per gram needed to melt aluminum is well known, the utility of particle beam BMD concepts rests on the less certain destructive effects at lower levels of irradiation. Source: Author

Table 3.4.—Effects of Particle Beam Irradiation

Harmful effect	Energy deposition (Joules per gram)
Disruption of electronics	0.01—1.0
Destruction of electronics	10
Detonation of propellants, high explosive	200
Softening of uranium and plutonium	hundreds
Melting of aluminum	1,000

Approximate energy deposition (radiation dose) required to produce various harmful effects in components of a missile booster and its payload. Many other effects, such as melting of glue and plastic and rate-dependent effects, might also be important.

SOURCE: Author

The target electrons that recoil from collisions with beam particles eventualy stop, and their energy appears as heat. The 100 MeV T° beam described above, depositing 100 J/cm² on an aluminum target, penetrates to a depth of 1.6 cm. The 1.6 cubic centimeter volume of aluminum that absorbs this 100 joules of energy weighs about 4 grams. The effect of the beam is therefore to deposit about 25 joules per gram throughout the first 1.6 cm of the target. The penetration depth is inversely proportional to the density of the absorbing material, so the same beam on a lead target would not penetrate as far but would deposit the same energy *per gram* as it did in aluminum (fig. 3.10).

The destructive effects of penetrating particle beams are therefore expressed in joules/gram deposited within the target rather than in joules/cm² on the surface of the target as with lasers. Table 3.4 shows the energy deposition needed to produce certain harmful effects. Melting the target is straightforward, but for the other effects at lower levels of irradiation the criteria are less clear. Heat effects in solid booster propellants and in the high explosive and special nuclear materials in warheads depend on the design of the target. Effects on electronics, particularly transient disruption of computer circuits when electrons are scattered by a passing proton, are poorly known and doubtless quite complicated and specific to the target. Other components not shown in table 3.4 —plastics, glue, guidance sensors— make for a very complicated analysis. What is more, the particle beam might have to suffer the attenuation of passage through, say, two layers of aluminum and a layer of plastic before reaching a sensitive component.

Uncertainties in the destructive or disruptive effects of small amounts of radiation from a particle beam weapon is the principal obstacle to stating what energy, current, and divergence angle would make this concept a candidate for boost-phase intercept.

Shielding to protect components from a neutral particle beam would necessarily be heavy but could still be an attractive countermeasure. It is discussed in Section 5.

An Orbiting Neutral Particle Beam System

A critical limitation of neutral particle beams is that they cannot be aimed through even the thinnest atmosphere—air so thin that even the x-ray laser beam could pass through easily. A neutral beam could not attack a Soviet booster until the booster reached at least 160 km altitude (versus about 80 km for the x-ray laser)[7]. Collisions

[7]The stripping cross section on oxygen is about 1.5 megabarns. Elastic scattering can also be important for beam loss, since the RMS scattering angle can be larger than the beam divergence. The author is indebted to Dr. George Guillespe of Physical Dynamics, Inc., in La Jolla for results of his Born approximation cross section calculations.

between air molecules and H^+ strip the electron from the H^0, and gradually all the remaining protons spiral off the beam axis into 200 km wide circles under the action of the earth's magnetic field.

An MX-like Soviet booster could be attacked between 160 km altitude and burnout at 200 km, a period of about 10 seconds. This short attack window means that the neutral beam cannot afford to dwell for long on each booster.

It is impossible to state with confidence the resilience of an ICBM booster to irradiation with a neutral particle beam. But it is likely that faith would have to be placed in degradation of electronics and other subtle effects, rather than in gross structural damage, for the beam weapon to stand a chance as an economical defense system (ignoring the issue of countermeasures entirely).

Consider again a battle station producing a 0.5 ampere beam of 100 MeV tritium (T^0) atoms with 2 microradian divergence. This beam carries 400 watts/cm² at 2 megameters range. To do structural damage to the outer few centimeters of a missile's body might take some 2 kJ/cm² (depositing 500 J/gm in 1.6 cm depth of aluminum, for instance), requiring 5 seconds of dwell time at this range. Since the available dwell time is only about 10 seconds, each beam could handle only two boosters. With a constellation size of almost 100 for 2 Mm range (fig. 3.4), this kill criterion results in a preposterous system where the U.S. deploys 50 space-based accelerators for every one Soviet booster deployed in one region of the U.S.S.R.

If the assumed Soviet booster hardness is reduced by 100 times, corresponding perhaps to transient upset of unshielded electronics, each satellite can destroy 200 boosters at 2 Mm range, meaning an overall tradeoff of one U.S. accelerator deployed for each two Soviet boosters deployed. Alternatively, the constellation can be thinned out to an effective range of 5 Mm, where each satellite at this range can destroy only 32 boosters but the constellation size is only about 16—still a one-to-two trade of battle stations for Soviet boosters. Such a system scarcely seems promising in terms of cost exchange.

Obviously the neutral particle beam would stand no chance of intercepting a fast-burn booster that burns out well within the protective atmosphere. Even an MX-like booster that flew a slightly depressed trajectory would be invulnerable.

A Theoretical Electron Beam System

Physical theory[8] holds out the prospect of one other type of beam besides the neutral particle beam. Under certain circumstances, an electron beam might be able to propagate through the extremely thin air of near-earth space without bending. In this scheme, a laser beam would first remove electrons from air molecules in a thin channel stretching from the battle station to the target, leaving a tube of free electrons and positive ions. The high-energy, high-current electron beam would then be injected into the channel. The beam electrons would quickly repel the free electrons from the channel, leaving the beam propagating down a positively charged tube. The attractive positive charge would prevent the electrons from bending off the beam path under the influence of the geomagnetic field and would also prevent the mutual repulsion of electrons within the beam from causing the beam to diverge. The result would be straight-line propagation to the target, where their effect would be similar in most respects to the neutral particle beam. This scheme will not work for a proton beam.

The physics of intense beam propagation through thin gases is so complex that experiments will be needed to determine whether this concept is even feasible in principle. If so, the concept would resemble the neutral particle beam, with the added requirement for the channel-boring laser and perhaps the ability to intercept boosters at slightly lower altitudes than the neutral counterpart.

[8] R. B. Miller, *The Physics of Intense Charged Particle Beams*, New York, 1982, ch. 5.

3.5 SPACE-BASED KINETIC ENERGY WEAPONS

Kinetic energy is the name given to the energy of a moving projectile. Use of this term makes ordinary weapons using aimed projectiles into "directed kinetic energy" weapons.

The phenomenology of high-velocity collisions between a projectile and a structure like a booster is surprisingly complex, but in general lethality is not an issue for kinetic energy boost phase intercept concepts. Rather, the problem is getting the projectile from its satelliite base to the ascending booster in time to make an intercept. Schemes where the projectile is carried by a small rocket launched from the satellite suffer most directly (leaving aside countermeasures) from a combination of the large number and large size of the rockets needed for adequate coverage. In particular, the most conspicuous public example of the kinetic energy approach, the High Frontier Project's Global Ballistic Missile Defense (GBMD) concept,[9] has extremely limited capability for boost phase intercept of current Soviet ICBMs and would have no capability at all against a future generation of MX-like boosters.

Kinetic Energy Concepts

Rocket attack of ICBM boosters is obviously not as novel as beam attack, but it entails rather more complexity than appears at first blush. The rocket needs radio or other guidance by long-range sensors on its carrier satellite (or other satellites) to direct it to the vicinity of its target, since it is impractical to put a long-range sensor on each rocket. Once in the vicinity of the target booster, the interceptor needs some form of terminal homing sensor and rather sizeable divert rocket motors. Homing on the plume of the ICBM booster is not straightforward, since attacking the plume will obviously not harm the booster: the booster body must be located in relation to the plume. These complications introduce opportunities for offensive countermeasures.

An alternative to rocket propulsion would be to expel the homing vehicles at high velocity from a gun. So-called rail guns use a clever scheme to convert electrical energy to projectile kinetic energy. Since a 10 kilogram projectile ejected with 5 km/sec velocity carries 125 megajoules of energy (the amount of energy expended by a 25 megawatt chemical laser in 5 seconds of dwell on a booster), the power requirements of the gun schemes are imposing. Providing chemical fuel or explosives to power a gun therefore involves the same magnitude of on-orbit weight as the chemical laser.

Doing away with the homing sensor and replacing the guided projectile with many small fragments is not an attractive alternative, since the needed fragments end up weighing far more than the guided projectile.

The Importance of Projectile Velocity

In the 300 or so seconds from launch to burnout of a slow-burning booster like the SS-18, the defensive rocket or other projectile must fly from its satellite to the path of the booster. Such a booster burns out at about 400 km altitude, so if the projectile wishes to use the entire 300 seconds of boost phase to travel to its quarry, it must make its intercept at 400 km altitude.

Suppose now that the projectile's rocket or gun launcher can give it a maximum velocity of 5 km/sec with respect to the carrier satellite. In the 300 seconds of available travel time to its target, the projectile cannot fly more than (5 km/sec) × (300 sec) = 1.5 Mm from its carrier. Each carrier therefore has an effective range of 1.5 Mm (fig. 3.11a).

Referring to figure 3.4, a constellation of about 240 carrier satellites are needed for continuous coverage of the Soviet Union. Since Soviet ICBMs are spread over much of the country, 10 or so of the carrier satellites might be able to participate in a defensive engagement. The absentee ratio is therefore about 24. The 10 satellites over the U.S.S.R. at the moment of a massive Soviet attack need to be able to handle all 1,400 boosters, meaning each satellite needs to carry 140 projectiles.

An idealized rocket accelerating a 15 kg guided projectile to 5 km/sec velocity would need to weigh about 80 kg (a real rocket with this capa-

[9] General Daniel O. Graham, *The Non-Nuclear Defense of Cities: The High Frontier Space-Based Defense Against ICBM Attack* (Cambridge: Abt Books, 1983).

Figure 3.11(a)

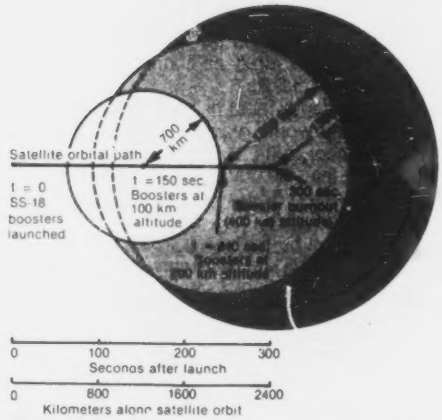
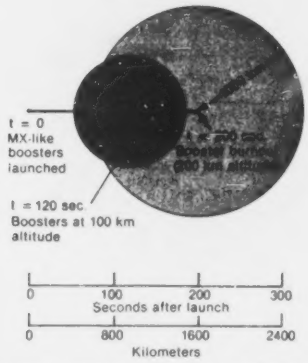


Figure 3.11(b)



(b) Same as (a), except the target is the faster-burning MX.

Figure 3.11 View from above (looking down on earth) of coverage by a satellite carrying kinetic energy boost-phase intercept vehicles. The satellite is deployed in a 400 km orbit. At time t=0, offensive boosters are launched. The satellite can make intercepts by shooting downward or wait until the boosters rise to their burnout altitude and fire nearer to the horizontal. The longer after launch the intercept is made, the farther the rocket intercept vehicles can travel from the satellite to make the intercept. Smaller circles thus correspond to downward firing, larger circles to horizontal firing. The satellite moves from left to right in accordance with its 8 km/sec orbital velocity. The area enclosed by all the circles taken together gives the total coverage of the satellite and determines how many satellites are needed in the worldwide constellation for continuous coverage of opposing ICBM fields. All dimensions are to same scale.
(a) The satellite-based kinetic energy interceptors are capable of 5 km/sec velocity relative to the satellite. The attack is on a slow-burning Soviet SS-18.

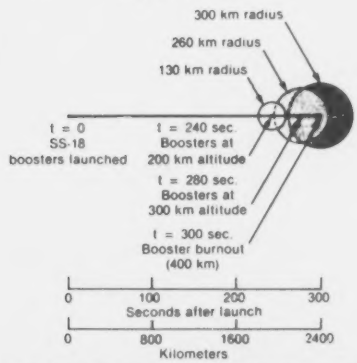
bility would weigh more like 200 kg). Each carrier satellite must therefore weigh (140) × (80) = 11,000 kg. Less than twice this weight can be carried by the space shuttle into the appropriate orbits, so establishing the total 240 satellite constellation requires over 120 shuttle launches in this highly idealized model with idealized rockets and weightless carrier satellites. (A more careful estimation of interceptor design would more than double this load.)

From this baseline, we can consider five excursions:

1. Suppose the velocity capability of the interceptor is doubled to 10 km/sec, doubling the effective flyout range to 3 Mm. At this range, 48 satellites complete the constellation, with perhaps as many as eight of them in position to participate in the engagement. Each of the eight satellites must handle 175 Soviet boosters.

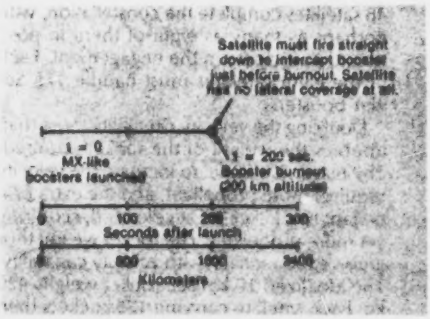
   Doubling the velocity capability more than doubles the weight of the rocket required. The reason is simple: to increase the velocity requires more propellant, and the extra propellant must itself be accelerated, requiring yet more propellant. The rocket weight thus grows exponentially with velocity capability. The idealized 10 km/sec rocket weighs 420 kg. Each satellite carrying 175 rockets then weighs 75,000 kg and requires some five shuttle launches to orbit. The result is that over 200 shuttle launches are required to orbit the entire (idealized) defense system. Increasing the velocity capability is therefore no escape from large on-orbit weights.
2. The current Soviet ICBM force consists largely of slow-burning liquid-fueled boosters distributed widely over the Soviet Union. Consider the consequences for the U.S. kinetic energy defense system if the Soviets de-

Figure 3.11(c)



(c) The High Frontier Global Ballistic Missile Defense (GBMD) concept, with intercept vehicles capable of only 1 km/sec velocity relative to the satellite. Intercept of SS-18. In the actual High Frontier proposal, the satellites are in 600 km orbits, giving them even less coverage than shown here.

Figure 3.11(d)



(d) The High Frontier concept has no capability whatsoever for boost-phase intercept of MX.

ploy 100 faster-burning MX-like boosters in one region of the country, so that defensive interceptors have less time to fly to their targets and only one satellite overhead participates in the engagement. MX burns out 200 seconds after launch, so each satellite has an effective range of 1 Mm, requiring a constellation of 400 satellites (fig. 3.11b). Each satellite must carry the 100 80-kg rockets needed to handle the attack. An exchange ratio of four 8,000 kg U.S. defensive satellites for every Soviet offensive booster deployed is surely an economic advantage for the U.S.S.R.

3. Soviet deployment of 1,000 Midgetman-like boosters would require a compensating deployment of 400 U.S. satellites, each weighing at least 80,000 kg. A system that forces the United States to such a response is clearly absurd.
4. Soviet fast-burn boosters would be totally immune to the kinetic energy defense system. An interceptor on a satellite in 400 km orbit (lower orbits shorten satellite lifetimes because of atmospheric drag) could not even descend straight down to the fast-burn booster's 100 km burnout altitude in the required 50 seconds, much less have any lateral radius of action.
5. Intercepting SS-18 or MX post-boost vehicles is clearly easier, from the point of view of flyout velocities, than boost-phase intercept. Satellites at 700 km or so altitude would have 500 seconds to fly out to meet the bus when it ascended to their altitude, giving a 2.5 Mm lethal radius.

In conclusion, a rocket-propelled kinetic energy system acting against today's Soviet ICBM arsenal (with no Soviet countermeasures) would require many heavy satellites and would be a dubious investment for the U.S. Soviet deployment of MX-like or Midgetman-like boosters would nullify the United States defense or force the U.S. to large investments in new satellites.

Analysis of the High Frontier Concept

The High Frontier Program[10] proposes a Global Ballistic Missile Defense (GBMD) using rocket propelled interceptors for boost phase intercept. This concept claims to have some utility, at least against the present Soviet ICBM arsenal.

The concept consists of 432 satellites (24 planes of 18 satellites in circular orbits inclined 65 degrees) at an altitude of 600 km. A velocity

[10]Ibid.

capability of 1 km/sec relative to the satellite ("truck") is attributed to the interceptor. The interceptors are apparently command guided to the vicinity of the target. The homing sensor is not specified, but short wave infrared homing on the hot rocket plume is implied.

Consider this concept defending against the SS-18 in its boost phase. Since the SS-18 burns out at 400 km altitude 300 seconds after launch, each GBMD satellite has a 0.3 Mm radius of action. Since the satellites are deployed at 600 km altitude, the interceptor must descend 200 km to make an intercept just before burnout, resulting in a lateral radius of action of 0.22 Mm (compare fig. 3.11c, where the satellites are assumed deployed at 400 km altitude). With a range this small, thousands of satellites would be needed worldwide for continuous coverage of Soviet ICBM fields. The High Frontier concept with only 432 satellites would therefore have meager coverage of Soviet ICBM fields.

The GBMD concept would have no capability whatsoever against an MX-like booster. Such a booster would burn out before the interceptor could reach it, even if the interceptor were fired straight down (fig. 3.11d).

It is possible that the High Frontier concept is designed for post-boost intercept rather than boost phase intercept. Its coverage for post-boost intercept, though greater than for boost-phase intercept, would still be only partial. The only example given in the description[11] of the system is of *boost phase* intercept of an SS-18, however. In this example the interceptor is launched 53 seconds *before* launch of its target booster, though no explanation is given of how the U.S. defense knows *in advance* the precise moment at which the Soviets would launch a given booster. This early launch allows the interceptor to reach its target seconds before burnout. Plume homing, a technique inappropriate for bus intercept, is also implied for the High Frontier concept. Post-boost intercept permits some RVs to be deployed on trajectories carrying them to the United States before intercept; and the entire bus, with its warheads, would continue on to the U.S. after the interceptor collision, with uncertain consequences.

It would therefore appear that the technical characteristics of the High Frontier scheme result in a defensive system of extremely limited capability for boost phase intercept of present Soviet ICBMs and no capability against future MX-like Soviet boosters, even with no Soviet effort to overcome the defense.

[11] Ibid., p. 103.

3.6 MICROWAVE GENERATORS

Microwaves are short-wavelength radio waves used in radar, satellite communications, and terrestrial communications relays. A number of ideas have been conceived for generating microwaves in space and directing them towards ascending ICBM boosters. The principal technical problem with this type of BMD, generator technology aside, is the uncertain effect the microwaves would have on their target.

The microwaves would propagate through the atmosphere unattenuated at all but the highest power levels. The weapon divergence angle would be very large, producing a spot many km wide at a few hundred km range. From these considerations the following concept emerges: As Soviet ICBMs lift off from their silos, a few microwave generators in space bathe the silo fields with microwaves.

At high power levels, as in a microwave oven, microwaves cause heating in many materials. But in the BMD scheme, the divergence cone is so large that even a prodigious amount of energy emitted from the generator would lead to very small energy deposition per square centimeter on the target (millions of times less than lasers). The microwave pulse received at the booster

would resemble the high frequency component of the electromagnetic pulse (EMP) from a high-altitude nuclear detonation. However, even weak microwaves can upset sensitive circuitry if they can reach it.

A metal skin on the booster would stop the microwave pulse altogether from reaching internal electronics. The microwave defense must therefore hope that some aperture or conduit is available into the booster, whether by design (as in an antenna), inadvertence, or poor maintenance. If so, and if the electronic circuitry is not or cannot be made resistant to disruption or burnout, the part of the booster's performance dependent on those electronics (perhaps accurate guidance) would be affected.

Because of the very uncertain lethality of microwaves, deployment of space-based generators (if they can ever be built) would be a harassing tactic rather than a confident-kill ballistic missile defense.

3.7 OTHER CONCEPTS

Other directed energy concepts suitable in theory for ballistic missile defense have been broached from time to time. Some of them are listed below. It is quite possible that in a few years time a revisit to this subject will find a new panoply of concepts enjoying the front rank of discussion.

1. **Short-wavelength chemical lasers** would combine the simplicity and efficiency of the HF chemical laser with the small mirrors of the short-wavelength excimer and free-electron lasers. Though some ideas have been advanced along these lines, no laser exists which can be said to be a candidate to fulfill this theoretical promise.
2. **Explosive-pumped lasers and particle beams** are said to be under study in the Soviet Union.[12] Such devices might possibly be quite compact, each bomb generating a single huge pulse for impulse kill of a booster. All these schemes are at a very early conceptual stage.
3. **Antimatter beams** would penetrate into a target just like ordinary particle beams, except that when the antiparticle reached the end of its range it would annihilate a particle in the target, freeing a large extra amount of harmful energy. Acceleration of antimatter beams is accomplished exactly as with particle beams, and laboratory beams of antimatter have been used routinely in pure research. One important difference is that antimatter is not freely available in the universe as is matter; the antimatter for the accelerator would have to be produced by the defense system, a formidable and complex undertaking. It is not clear that the extra energy released in the target by an antimatter beam would justify the trouble of producing the beam.

[12] *Aviation Week and Space Technology*, July 28, 1980, p. 47.

Section 4

OTHER ESSENTIAL ELEMENTS OF A BOOST-PHASE INTERCEPT SYSTEM

The previous section treated only the defensive weapon itself, the so-called "kill mechanism." But if beam weapons ever evolve to the point where deployment is a serious possibility, other elements of the overall defensive system will emerge as equally important determinants of cost and level of protection. After all, the interceptor missile in traditional BMDs has not been the central focus of attention or technical debate since the 1950's, when it became clear that a "bullet could hit a bullet." Discussion of BMD at that point passed to the difficult issues of radar performance, data processing capability, and vulnerable basing of defensive components—issues that had nothing to do with the kill mechanism. In a similar manner, the other essential elements of a boost-phase intercept system will figure more prominently in discussion of boost-phase BMD if and when the kill mechanisms—lasers, mirrors, accelerators—are in hand. These other essential elements introduce their own technological problems and opportunities for offensive countermeasures. If traditional BMDs are any guide, provision of a kill mechanism will be just the beginning of making an efficient, robust defensive system.

4.1 TARGET SENSING

Locating and tracking an ICBM booster with enough precision to aim a directed-energy weapon is not as straightforward as is sometimes supposed. It is true that booster motors emit hundreds of kilowatts of power at short- and medium-wave infrared (SWIR and MWIR) wavelengths of a few microns. Sensors can detect these plumes at great distances from the earth. Plume sensing is used today for early warning of missile attack to support launch of bombers and airborne command posts and launch under attack of ICBMs.

To be useful for directed-energy BMD, however, the sensor must localize the booster within an area as small as the beam spot. Otherwise the beam would have to sweep wastefully back and forth over the area of uncertainty. Small divergence beams must therefore be accompanied by sensors with small angular resolution.

Diffraction limits the angular resolution of a sensor in the same way it limits the divergence angle of a laser. A large infrared telescope with 5 m diameter mirror observing MWIR booster emission at 4 micron wavelength would have angular resolution no more precise than a microradian. Such a sensor affixed to each battle station in a defensive constellation would localize ascending boosters to within a spot 5 m wide at 5 Mm range. At this range, the (illustrative) systems described in Section 3 have spot sizes: 1.5 m for the HF laser, 0.6 m for the ground based laser, 10 m for the neutral particle beam, and 100 m for the x-ray laser. Even a large infrared sensor on each battle station would therefore be inadequate for directing the laser beams at a point source of MWIR light, marginal for directing the neutral particle beam, and adequate for directing the x-ray laser. The actual situation would be worse still, since the booster is not a point source. The booster plume would be larger than the laser or particle beam spots, and the booster body would need to be located in relation to the plume to avoid wasting beam time attacking the plume.

For directed-energy weapons with small divergence angles, therefore, sensing the conspicuous rocket plume is inadequate. Another kind of sensor must be introduced into the BMD system. For finer angular resolution one looks to shorter wavelengths, in the visible or ultraviolet. At these wavelengths the sensor must provide its own illumination. A so-called laser radar or ladar is the only practical solution. In a ladar, a low-power

visible or ultraviolet laser shines on the booster body, and a telescope on board the battle station senses the reflected light.

Besides the annoyance of a new laser and new sensor, the necessary introduction of ladar into the boost-phase system creates opportunities for the defense to spoof and blind the offensive sensor.

Kinetic energy systems do not need precision long-range sensing, since the rocket or guided projectile homes on the target when it comes within short range. The terminal homing might involve deducing the location of the booster body in relation to its MWIR plume, homing on low-power laser light shined from a defensive satellite and reflected from the target, or some other method. These homing methods are susceptible to countermeasures.

Though this Background Paper treats only intercept of the booster proper, it is worthwhile pausing to consider tracking of the post boost vehicle or bus. The low thrust levels of the post boost vehicles's rocket motors, their intermittent operation, the possibility of dimming them with propellant additives, and the possibility of building decoys with small rocket motors all suggest that MWIR plume sensing is not practical for post boost intercept. The alternatives are ladar or radar, suggesting again many opportunities for countermeasures.

4.2 AIMING AND POINTING

The directed-energy beam must be aimed and stabilized as accurately as it is collimated. If the beam waves around too much, the effective divergence increases, and the beam wastes energy missing the target. The mirrors or other mechanism steering the beam must be stabilized despite vibrations in the battle station caused by the beam's large power source.

In the 15 milliseconds the beam takes to travel from the battle station to a booster 5 Mm away, the booster moves about 50 m. A narrow beam must therefore lead the target. In one second of dwell time, the target moves several km; the beam must remain on the target, sweeping through the sky at the necessary angular rate while still maintaining its aim and jitter control.

4.3 INTERCEPT CONFIRMATION

A desirable, though perhaps not essential, function of BMD systems is confirmation that an attempted intercept succeeded. This function is sometimes called "kill assessment." Intercept confirmation would allow the beam to move onto subsequent boosters with more than a statistical estimate that its previous task was accomplished. Structural damage to the booster would presumably be revealed by an erratic course or burn pattern, though it might be difficult to say in advance exactly what the sensor's view of the wounded booster would be. Subtle damage inflicted by a particle beam or microwave generator might not be visible. Damage to a bus would be difficult to assess and interpret if the debris, including RVs (perhaps arranged by the offense to separate from the bus under extreme circumstances), continue on their ballistic course to the continental United States.

Related to intercept confirmation, and ultimately more serious, is the question of determining whether the beam is missing the target (perhaps by slight misalignment of sensor and beam boresights, miscalibration of aiming mechanisms, etc.) and, if so, by how much and in what direction. It might be possible to observe a glowing column of air where a laser beam passes through the at-

mosphere. Some clever but elaborate schemes have been devised to track a neutral particle beam. Obviously each new complication added to the defensive system potentially creates new opportunities for offensive countermeasures.

4.4 COMMAND AND CONTROL

The crucial infrastructure of command and control of a complex system is always the last to take shape, since it integrates the workings of all the separate components. It is easy to ignore the difficulty of accomplishing this last step at this early stage when the other components of a boost phase system are not yet remotely in hand. The command and control system of a boost-phase intercept system would comprise communications links among its far-flung components, data processing to support sensors and battle station operations, and "battle management" software incorporating all the instructions and decisions needed to run the defensive engagement and to coordinate the defense with U.S. offensive forces.

Communications and data processing are two areas of technology where there is the least pessimism—looking two or so decades into the future when boost-phase systems could presumably be deployed—that technology will be able to meet the needs of directed-energy defenses. Compact, lightweight, and rapid data processing hardware is virtually assured, though interesting questions attend on hardening, reliability, and lifetime in space. Software would be expensive and would introduce issues of reliability and security from programmer sabotage. Satellite-to-satellite communication via extremely high frequency radio and laser offers high data rates and virtual immunity to jamming from earth or from space.

Command and control for BMD does introduce two interesting issues to which technology cannot provide an answer. The first is the impossibility of testing the whole defense system from end to end in a realistic wartime setting. Unlike the air defense systems of World War II, which learned through attack after attack to exact kill rates of several percent, the BMD system would have to work near perfectly the very first time it was used. The second issue is the likely need for the defense to activate itself autonomously, since there would be no more than a minute for human decision.

4.5 SELF-DEFENSE

Consideration of anti-satellite (ASAT) attack (see Section 5.1), and analogy with traditional BMD systems (where vulnerability of key radars, data processors, and other components is usually the chief limitation on defense performance) suggest that self-defense mechanisms could well end up being a large part of the defense system. These mechanisms could include shields, escort weapons, and countermeasures to ASAT sensors. Unless and until a credible overall approach to satellite survivability is found, one cannot specify the needed hardware.

Ground-based BMD lasers and pop-up x-ray lasers would obviously need to be protected from precursor attack by cruise missiles and other delivery systems.

4.6 POWER SOURCES

Chemical lasers, x-ray lasers, and rocket-propelled kinetic-energy interceptors have power sources integral to the weapon, but excimer lasers, free electron lasers, neutral particle beams, and rail guns would need sources of electrical power and the equally important means to convert electricity into a form usable by the weapon ("power conditioning"). Space basing obviously complicates the task. Large commercial power plants on the ground produce about 1,000 MW of power, and directed energy weapons might require hundreds of MW. On the other hand, the power plants on defensive satellites need not work reliably for many years but only once for a short time, and they need not be very highly efficient. The three alternatives for space power are fuel burning, explosives, and nuclear power. Starting up a large power source in seconds from a condition of dormancy poses some interesting design issues.

Section 5

COUNTERMEASURES TO BOOST-PHASE INTERCEPT

Countermeasures that limit the effectiveness of traditional ballistic missile defenses—decoys, radar blackout, defense suppression, etc.—are well known. A comparable set of countermeasures, no less daunting for being less familiar, faces the designer of boost-phase defenses.

The need to resort to countermeasures imposes a cost on the offense. This cost is measured in money to build more or specialized offensive hardware, but also in the time needed to do so, in constraints upon the type of attack the offense can incorporate in its nuclear planning, and in the confidence with which it can predict a "successful" outcome of the strike.

Every BMD system actually proposed for deployment would be accompanied, at least ideally, by, first, an analysis of its degradation in the face of an improving Soviet offense and, second, by an analysis of how much it would cost for the United States to improve its defense in such a way as to avoid being overcome.[1]

[1]See *Ballistic Missile Defense*, ed. Ashton B. Carter and David N. Schwartz (The Brookings Institution, 1984), ch. 4.

Figure 5.1

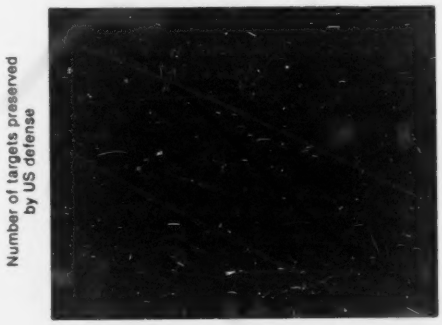

Number of targets preserved by US defense
Soviet investment in offense
(more ICBMs, new types, special countermeasures, etc.)

Fig. 5.1. Schematic drawdown curve, showing how the performance of a BMD system degrades as the size and sophistication of the attacking force increase.

Figure 5.2

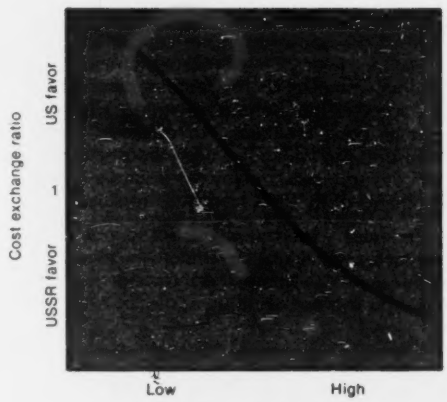


Fig. 5.2. The marginal cost exchange ratio measures the outcome of a race between the Soviet offense to enhance its penetration and a U.S. defense to maintain its level of protection. In general, modest defense goals (e.g., "preserve 40 percent of the targets") are easier to sustain than high goals ("preserve 95 percent of the targets") against improvements in Soviet offensive forces, including deployment of countermeasures.

The first analysis would be expressed in a drawdown curve such as that shown in figure 5.1. The Soviets can overcome the defense and destroy a large number of U.S. targets, but to do so the Soviets must "pay" an "attack price."

The second analysis would be encapsulated in the cost exchange ratio. The marginal cost exchange might be defined as follows: "Assume that in the year 2000 the U.S. defense and Soviet offense have evolved so that each has a certain level of effectiveness. Suppose the Soviets wish to improve their position and the U.S. resolves to maintain the status quo. Which side spends more in the competition?" For example, suppose every time the Soviets add 100 ICBMs to their arsenal, the United States has to add 20 satellites to its defensive constellation to intercept them: Which costs more, 100 ICBMs or 20 satellites?

In general, high levels of defense performance are harder to enforce in the face of offensive improvements than low levels: this important fact is shown schematically in figure 5.2 (see also Section 8.2).

All of the boost-phase intercept schemes discussed in this report are in such an early stage of conceptualization that nothing remotely like the analyses represented by Figures 5.1 and 5.2 can be done for them. Nonetheless, countermeasures are known for every boost-phase system devised, and in many cases simple heuristic estimates of the cost tradeoffs are suggestive.

Technical experts disagree not so much about the facts and calculations underlying these countermeasures as about the interpretation to be given to them. Should an apparently fatal flaw uncovered at this early stage of study of a defensive concept be decisive, or should work (and the inevitable expectations that accompany it) continue on the chance that a new idea will turn up to rescue the concept? Would the Soviets really resort to a subtle tactic or exotic piece of hardware as a confident basis for their nuclear policy? Some analysts see BMD as a way of "forcing" the Soviets to take a certain direction in their pursuit of the arms race, e.g., away from large, slow-burning MIRVd boosters to single-warhead Midgetman-like boosters. In this view, defeat of the BMD is purchased at the price of a theoretically more stable and desirable Soviet offensive posture. All these questions of judgment loom large in making a final assessment of a given countermeasure.

5.1 ANTI-SATELLITE (ASAT) ATTACK, INCLUDING DIRECTED-ENERGY OFFENSE

All boost-phase intercept BMD concepts have crucial components based in space. Even a pop-up defense would need warning and very probably target acquisition sensors on satellites over the Soviet Union. Ground-based laser defenses would have mirrors and sensors—their most fragile components—in space. Vulnerability of these satellites is a cardinal concern because their orbits are completely predictable (they are in effect fixed targets), they are impractical to harden, conceal, or proliferate to any significant degree, and because successful development of effective directed-energy BMD weapons virtually presupposes development of potent anti-satellite (ASAT) weapons. ASAT is the clear boost-phase analogue of familiar defense suppression tactics against traditional BMDs, where attack is first made upon the defensive deployment (especially fixed radars) and then upon the defended targets.

The interplay of ASAT techniques—missiles (nuclear or conventional), space mines, directed energy—and satellite defense (DSAT) techniques is a complex one. It is difficult to generalize, but in the specific case of large battle stations in low-earth orbit it would seem that the advantage is very likely to lie with ASAT, not DSAT. For one thing, the offense need not destroy a large number of defensive satellites, but only "cut a hole" in the defensive constellation. Second, the traditional military refuges all offer complications: concealment from radar, optical, infrared, and electronic detection, while possibly successful for small payloads in supersynchronous orbits, is impractical for large, complex spacecraft at most a few thousand km from the earth's surface; decoy satellites must generate heat, stationkeep, and give status reports, and they are in any event only useful if the ASAT designer is somehow restrained (perhaps by cost) from shooting at all suspicious objects; hardening imposes weight penalties, and massive shields could interfere with the constant surveillance and instant response required of the defense; proliferation is useless for expensive satellites facing inexpensive ASAT methods. As a consequence, discussions of DSAT for BMD battle stations usually emphasize large keep-out zones around the satellites and active self-defense. A third reason why ASAT is likely to prevail over DSAT is that possession by the offense of the same type of directed energy satellites used by the BMD probably assures successful first

strike. Fourth, the Soviets would pick the time and sequence of their attack, and it would occur over Soviet territory.

Two rather novel ASAT threats are worthy of note. The first is the x-ray laser itself. The x-ray laser, if it could be developed, would constitute a powerful space mine. Because of its long range, it could lurk thousands of km from its quarry. The Soviets might also launch x-ray lasers a few seconds before launch of their main attack. Recall that the well-known phenomenon of bleaching (see Section 3.3) would probably allow such x-ray lasers to shoot out of the atmosphere at a U.S. x-ray laser defense, but the U.S. x-ray lasers could not shoot down into the atmosphere at the ascending lasers.

A second ASAT tactic, discussed for many years, imagines the Soviet Union exploding nuclear weapons at high altitudes in peacetime with the intent of shortening the orbital lifetimes of the U.S. defensive satellites. The nuclear bursts inject further radiation into the van Allen belts that circle the earth's equator from about 1,500 to 10,000 km altitude. Satellites (more likely carrying sensors than weapons at these altitudes) passing through the belts accumulate a radiation dose that gradually degrades electronics, sensors, and optical surfaces. This possibility, if taken seriously, would require defensive satellites designed to withstand rather substantial accumulated radiation doses.

A detailed treatment of the ASAT problem is beyond the scope of this Background Paper. The following "parable" illustrates some of the problems encountered in trying to ensure the survivability of a defensive constellation, taking the 20 MW HF lasers of Section 3.1 as an example.

The United States deploys the HF lasers in this hypothetical system in low orbits at 1,000 km altitude. Higher altitude would place them too far from their targets. This is unfortunate: higher altitude (say, between 2,000 km and semisynchronous orbit at 20,000 km) would move the satellites further from ground-based ASAT weapons and put them into lesser-used orbits where staking out a sanctuary would involve less interference with foreign spacecraft.

Suppose the battle station designers have succeeded in the considerable task of making the satellites resilient to multi-megaton nuclear space mines (bombs, not x-ray lasers) as little as 100 km away. To keep all Soviet spacecraft (i.e., all potential mines) at least 100 km away, the United States claims for itself the orbital band between 900 and 1,100 km altitude. Perhaps the Soviets are awarded some other orbital zone for their own military purposes. The United States establishes the following rules in its zone: 1) No foreign spacecraft may transit the zone without prearrangement; 2) All transiting vehicles must remain at least 100 km from all U.S. battle stations, passing through a "hole" in the constellation; 3) Foreign spacecraft failing to obey these rules may be destroyed by the U.S. lasers.

Consider first a Soviet kinetic energy ASAT deployed at 1,100 km altitude, just outside the U.S. keepout zone. Suppose the rocket interceptors on the Soviet satellites have the same propulsive capacity—one km/sec—as the proposed High Frontier Global BMD system. The Soviet ASATs are then just 100 seconds away from the U.S. lasers. The U.S. lasers must therefore be very vigilant to avoid surprise attack. Fortunately, at 100 km range the 20 MW laser with 10 m mirror would burn up even a heavily hardened ASAT rocket in short order. Since starting up the main laser for self-defense might be awkward, wasteful of fuel, or time consuming, each U.S. battle station might be escorted by a satellite carrying a smaller laser or rockets for self-defense.

A constellation of Soviet 20 MW, 10 m HF lasers (the same technology as the U.S. lasers) at 1,100 km is another matter. These lasers could attack the U.S. lasers seconds before launch of a Soviet ICBM attack. The United States would have to keep these Soviet spacecraft *thousands* of km away from the U.S. constellation. That is, the United States would have to dominate near-earth space. Suppose the United States does so.

Now the Soviets build a fleet of pop-up x-ray lasers. These lasers climb to 100 km or so altitude, where information radioed to them from the ground allows them to point their rods at the U.S. lasers and detonate. The Soviets have had poor

success at building an x-ray laser; theirs are 100 times less bright than the ideal x-ray laser described in Section 3.3. Nonetheless, by pointing all its lasing rods at the same target, a Soviet x-ray laser can destroy a U.S. laser battle station at 10 Mm range. The U.S. chemical lasers attack the Soviet x-ray lasers as they ascend, but at this range long dwell times are required to destroy the Soviet lasers. By launching enough x-ray lasers simultaneously, the Soviets succeed in getting some to 100 km altitude, where they can shoot out through the thin atmosphere, before the U.S. lasers can destroy them. In this way, the Soviets "punch a hole" in the U.S. defensive constellation. (At a minimum, the Soviet ASAT attack consumes precious laser fuel aboard the U.S. battle stations.)

Just to make sure, the Soviets also deploy some powerful ground-based excimer or free electron lasers to destroy the U.S. battle stations as they orbit helplessly through space.

5.2 FAST-BURN BOOSTERS

Shortening the boost time and lowering the burnout altitude is easily accomplished at little sacrifice in useable ICBM payload (see Section 2). Shorter boost time increases the number of lasers needed for space-based laser or ground-based laser systems to handle simultaneously launched boosters. Short burn time makes rocket-propelled kinetic energy systems impractical, since the radius of action of each satellite becomes too small. Short burn time, together with low burnout altitude, would severely compromise the effectiveness of x-ray lasers popped up even from subs near Soviet shores. Low burnout altitude nullifies the neutral particle beam, which cannot penetrate very far into the atmosphere.

Fast-burn boosters would therefore be a potent, even decisive, countermeasure against almost all concepts for boost-phase intercept.

5.3 COUNTER C³I TACTICS

Countermeasures to the crucial functions of target sensing and command and control are a relatively unexplored, but probably key, problem area for directed energy BMD. In the case of terminal and midcourse defenses, the issues of decoy discrimination, confusion caused by chaff and aerosols, radar blackout and infrared redout, radar jamming, and traffic handling have always been and remain central limitations. It is likely that analogues will be found for boost-phase systems. Devising countermeasures requires a degree of specificity about the nature of the defense system which cannot be provided in the present conceptual stage. There follow a few examples of C³I countermeasures, by no means an exhaustive list.

A first point to note is that sensors are likely to be the most vulnerable part of a defensive satellite. A laser shined into an optical sensor can daze or injure the focal plane elements, though viewing in frequency bands absorbed by the atmosphere offers protection from ground-based lasers. Mirrors would be very susceptible to damage from a Soviet x-ray laser. A Soviet neutral particle beam could disrupt electronic circuits on U.S. satellites. Radiation pumped into the van Allen belts by nuclear bursts would affect sensors and electronics.

A single nuclear burst causes the upper atmosphere to glow brightly over areas 100 km in radius for over a minute. Calculated radiances[2] are large enough to cause background problems for MWIR tracking sensors.

[2] S. D. Drell and M. A. Ruderman, *Infrared Physics*, Vol. 1, p. 189 (1962).

Some directed-energy weapons produce spots only meters wide at the target, requiring target sensing to commensurate precision via laser radar (see Section 4.1). Laser radars sense laser light reflected from the target. A small corner reflector affixed to the target would produce a bright glint of reflected light, as would other corner reflectors launched on sounding rockets, ejected from the target, or attached to the target by extendable booms. These proliferated corner reflectors might force the beam weapon to attack them all.

The homing sensor of a kinetic energy interceptor could be susceptible to spoofing, depending on its type.

Jamming satellite-to-satellite communications crosslinks is probably *not* an effective offensive tactic, since the links would have narrow beamwidths, requiring the jammer to locate itself directly between the two satellites; and wide bandwidths, requiring high jammer power.

5.4 SHIELDING

A degree of shielding from lethal effects is practical for all but the kinetic energy weapons but involves in each case different methods suited to the different physical principles at work. At the same time, large uncertainties plague all lethality estimates, and further testing and study will be needed before firm answers can be given for any of the systems. For thermal kill with a laser, a solid booster designed with some attention to a laser threat can probably easily be made to withstand 10 kJ/cm^2. Application of a gram or so of heatshield material on each square centimeter of booster skin can probably triple this hardness, and spinning the booster enhances hardness by another factor of three. Heatshield material is ablative, meaning that when heated it burns off, carrying away the heat in the combustion gases rather than conducting it through to the missile skin underneath. A factor of nine increase in hardness requires the defensive laser to dwell on the booster nine times as long or to approach within a third of the range. Though hardening a new booster from scratch is clearly easiest, there is no serious impediment to retrofitting ablative coatings on existing boosters. Applying a gram per square centimeter of ablative material to the entire body of the MX missile would require removing several RVs from the payload, since the coating would weigh well over 1,000 kg.

An interesting possibility, requiring further study, would involve injecting into the atmosphere or producing from atmospheric gases, either throughout the ICBM flyout corridors or in the vicinity of individual boosters, smoke or laser absorbing molecules. Likewise, dust clouds raised by groundburst weapons (delivered by cruise missiles or by ICBMs that "leak" through the defense) might cause serious propagation problems for the ground-based laser scheme.

Hardening to an x-ray laser involves quite different physical principles. Recall that the x-ray energy is deposited in a paper-thin layer of the booster skin. The superheated layer explodes, applying an impulsive shock to the booster. Obviously a paper-thin shield between the booster and the laser will stop x-rays from reaching the booster wall. But the problem then becomes the debris from the exploding shield. One can easily show by calculation that the debris applies virtually the same impulse to the wall of the booster as would result from direct impinging of the x-rays! A number of schemes can be devised to divert the debris from striking the booster, but these require more study to implement in practice. One factor acting in favor of the shield designer is that the booster is not vulnerable to x-ray attack until it leaves the atmosphere. The lightweight shields therefore do not have to be designed to suffer large drag forces.

The neutral particle beam presents a third distinct type of hardening problem. The energetic beam particles penetrate into the target, and several centimeters of lead would be required to stop them. Since the beam cannot penetrate very far into the atmosphere, only the upper booster

stages need be hardened. But if the third stage, say, of the MX were covered with a few grams per square centimeters of lead, the shielding alone would weigh as much as several RVs. On the other hand, if the neutral particle beam is only designed to disrupt or damage sensitive electronics, but is not powerful enough to do damage to other parts of the missile, only the sensitive components need be shielded. The weight penalty then becomes small.

It is possible that the offense can extend the protection of the upper atmosphere against the neutral particle beam by exploding a few nuclear weapons at moderate altitudes before the beam can reach them. The detonations heat the air, which rises, effectively elevating the altitude at which the neutral beam is stripped of its remaining electron and bent in the geomagnetic field. This phenomenon is called atmospheric heave. It is as yet unresolved whether atmospheric heave will loft enough air to make a difference to the engagement altitude of the x-ray laser.

5.5 DECOYS

There is no way for a decoy booster to mimic closely the hot exhaust plume of an ICBM booster except by burning a similar rocket stage. One can add chemicals to the propellants to brighten a small booster's plume and dim the ICBM's, but as a first approximation a faithful decoy must be another booster.

Decoy tactics are therefore not as attractive for boost-phase intercept systems that use plume sensing as they are for midcourse and reentry defenses, where large numbers of cheap, lightweight decoys can be carried with negligible offload of RVs. Still, the usefulness of a decoy depends not on how expensive the decoy is, but on how the cost of the decoy compares to the cost of the defense that intercepts it. Booster decoys would not be nearly as expensive as true ICBMs, since they carry no warheads or precision guidance system, they need not be highly reliable, and they might not need to be based in underground silos but can be deployed above ground next to the ICBM silos.

Some of the boost phase intercept systems must grow in the number of their deployed battle stations in direct proportion to the number of Soviet boosters. Deploying one decoy (with a dummy payload) next to each of the 1,400 Soviet ICBM silos might cause the United States to have to double the number of battle stations overhead (and thus worldwide, multiplying by the absentee ratio) to handle the extra traffic. If the defensive battle stations were at all expensive, this would be an unpleasant prospect for the United States.

Many directed energy schemes would not rely on plume sensing alone (see Section 4.1). Decoy tactics against laser radars (including corner reflectors; see Section 5.3) might be much easier for the offense to implement than mimicking the booster plume.

5.6 SALVO RATE

The worst-case attack for all the boost-phase intercept schemes is massive, simultaneous launch of all Soviet ICBMs. The defensive satellites over the Soviet silo fields at the moment of launch then have to handle the entire attack.

A more leisurely salvo rate would allow laser and particle beam defenses that have to dwell on their targets more time to handle more targets. Slow attack also allows pop-up defenses to climb to intercept position. An attack drawn out 10

minutes or longer allows fresh defensive satellites to move along their orbits into position overhead, replacing depleted satellites. The orbital period of satellites in low earth orbit is about 90 minutes. If there are 8 to 10 satellites in each ring of the defensive constellation, satellites replace one another every 10 minutes or so.

An exception to this simultaneous-launch worst-case analysis is the x-ray laser, which delivers all its energy in an instant.

There would seem to be few military penalties for the Soviet Union to adopting plans to launch all their ICBMs in large attack within a few minutes. Indeed, if one of their objectives is to destroy U.S. ICBMs in their silos, rapid attack would be the best Soviet choice. Some, though not all, of the successful attacks that could be mounted on Closely Spaced Basing (Densepack) for MX involve very slow or intermittent salvo rates, however.

More importantly, in many circumstances the Soviets might wish to launch only a fraction of their ICBM force. A U.S. defense deployment too small to intercept all boosters in a massive attack would still be able to handle a small attack. A light defense might therefore establish a "threshold" of attack intensity below which Soviet boosters would face intercept. This prospect is discussed further in Section 9.

5.7 OFFENSIVE BUILDUP

The most straightforward way for the offense to compete with the defense is to grow in size. If for every new ICBM added to the Soviet arsenal, the U.S. defensive satellite constellation must be augmented at comparable or greater cost, the Soviets could challenge the United States to a spending race to their net advantage. On the other hand, if the defensive buildup is cheaper than the offensive buildup, the defense forces the offense either to accept limitations on its penetration or to resort to qualitative changes in its arsenal.

As an illustrative example of such a cost tradeoff, consider the hypothetical HF chemical laser system described in Section 3.1. Each laser in that system requires 1.7 seconds of dwell time to destroy a booster. During the 200 seconds of boost, each laser overhead can therefore destroy 120 boosters. But for each laser overhead, 32 are needed worldwide. Suppose now that the Soviets deploy, in one region of the U.S.S.R., 1,000 Midgetman missiles at a cost of 10 to 20 billion U.S. dollars (see Section 2). The U.S. defense now needs to be "beefed up" with addition of $(1{,}000) \times (32)/120 = 270$ laser battle stations. A tradeoff of more than one complex U.S. satellite, launched and maintained on orbit, for every 4 Soviet boosters (or decoy boosters) deployed on the ground would certainly appear to be a losing proposition for the United States. This is true even though the hypothetical HF laser system represents a very favorable outcome of laser technology.

Note that Soviet deployment of new ICBMs in one region of the Soviet Union, within coverage of only a single U.S. satellite, gives them the best leverage in the cost exchange.

5.8 NEW TARGETING PLANS

Truly efficient ICBM defenses would presumably force upon the superpowers a stricter attention to targeting priorities. With thousands of warheads in today's arsenals able to be literally lobbed into any target area unimpeded, the superpowers have less need to be discriminating or parsimonious in their nuclear targeting. Such a shift might have both desirable and undesirable

consequences. For example, the offense might decide that in view of the cost of countermeasures it could no longer afford to threaten the other side's ICBM silos. The warheads "freed up" from the countersilo mission might then be dedicated to heavier targeting of other aimpoints (perhaps cities) as a hedge against poor penetration. How the superpowers would greet these hypothetical defenses is not clear, but it is probably quite wrong to imagine future defenses acting against offensive forces targeted according to the war plans of today.

5.9 OTHER MEANS OF DELIVERING NUCLEAR WEAPONS

One additional Soviet response to an efficient defense against their ICBMs would be increased emphasis on submarine-launched ballistic missiles (SLBMs), bombers, cruise missiles, and whatever novel methods time and ingenuity might in the future devise for introducing nuclear weapons to the United States. As defenses forced up the cost-per-delivered-warhead of ICBM forces, these other methods would become relatively more attractive. Though they would sidestep the BMD, these delivery means have higher pre-launch survivability than ICBMs, and bombers and cruise missiles have longer times of flight. These attributes are usually seen as "stabilizing." Shifting the emphasis of the arms competition away from ICBMs is therefore sometimes viewed as adequate payoff for the BMD effort.

SLBMs would obviously be vulnerable to the same boost-phase weapons as ICBMs. The same worldwide coverage, reflected in the absentee ratio, that plagues the anti-ICBM cost exchange means that orbiting boost-phase defenses threaten SLBMs the world over. However, midcourse and terminal tiers of a layered defense would in general have much less capability against SLBMs, because of the latter's short time of flight, possibly depressed trajectory, and uncertain direction of attack. Thus SLBMs could conceivably enjoy greater penetration of a layered defense than ICBMs.

If one takes an optimistic view of emerging defensive technologies, or if one contemplates technological "breakthroughs," it is at least conceivable that such developments will spawn new ways of delivering or aiding the delivery of nuclear weapons as well as new ways of interdicting them.

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Section 6
A WORD ON "OLD" BMD AND "NEW" BMD

No one knows whether directed-energy weapons can be built with the characteristics assigned to the hypothetical systems of Section 3. Even if such systems can be built, it is not clear that their performance will match, much less exceed, the performance of terminal and midcourse BMD systems in level of protection (attack price) and in cost relative to offsetting offensive improvements. The boost-phase BMD systems receiving so much attention today were a year ago at the periphery, to say the least, of technical discussion of missile defense. It is important not to lose sight of the status of traditional reentry and "advanced" (as they were called a year ago) "overlay" midcourse BMDs.

Naturally, the promise of the better-understood terminal and midcourse systems does not seem so grandiose, nor the flaws so clear-cut, as they do for the conceptual boost-phase defenses discussed in this Background Paper. Sounder technical assessments can be made of the "old" BMDs than of the "new" concepts. Rough concepts gloss over all the difficult design problems that inevitably limit achievable performance and turn up serious problems; nonetheless, identifying potentially unsolvable problems at this early stage of study does not mean they will remain insurmountable. BMD architectures incorporating boost-phase intercept are not known to be able to perform better, dollar-for-dollar, than BMD architectures incorporating only midcourse and reentry intercept. They are just not known to be worse. Terminal defense systems have been studied, designed, and tested for years, and it is generally agreed that such systems, acting alone, can enforce a modest attack price of between 2 and 8 RVs (perhaps equivalent to 20 to 80 percent of a booster) per defended aimpoint. Though their capabilities are modest, reentry and midcourse defenses suffice for modest defensive goals. There is no need to incur the technical risk of "new" boost-phase intercept schemes unless one aspires to levels of performance clearly beyond those possible with "old" concepts.

Many of the "new" concepts for boost-phase intercept are not new at all. They have been studied and discussed in one form or another for 20 years. Conversely, there are some new ideas for improving terminal and midcourse BMDs.[1] The spirit of technical optimism that accompanied the new emphasis on boost-phase intercept in the past year affected thinking about "old" BMD as well.

For terminal defense systems, the new features receiving attention are, first, non-nuclear warheads on interceptor missiles and, second, airplane-borne infrared sensors as supplements to ground-based radars. The principal benefit of non-nuclear intercept is that interceptors can be deployed nationwide without public concern about the safety of defensive nuclear warheads. Non-nuclear kill does not permit the defense to avoid all the disruptive effects of nuclear bursts, however, since the offense can still arrange for RVs to detonate when they sense interceptor impact ("salvage fuzing"). The miss-distance/weight relationship of the non-nuclear warhead requires the interceptor to approach more closely to the RV, and this in turn requires a homing seeker on the interceptor. Terminal homing obviously creates new opportunities for offensive countermeasures.

Airborne optical sensors obviously do not suffer radar blackout, but they can suffer the analogous problem of infrared redout. Decoy discrimination remains a problem, though it acquires some interesting new features. Details of these new aspects of terminal BMD are obviously classified. Though important, these aspects are fairly straightforward extensions of traditional techniques rather than revolutionary "breakthroughs."

New thought about midcourse defense focuses on alleviating the Achilles' heel of systems that use infrared sensing to support intercept in space: the ease with which the offense can accompany attacking RVs with clouds of decoys. One approach receiving attention is simply to cheapen the interceptor and shoot at everything, RVs and decoys alike. Another is to probe the attacking

[1] See Julian Davidson, "BMD: Star Wars in Perspective," *Aerospace America*, January 1984, p. 78.

objects with an active sensor, rather than relying on their thermal emissions, in the hope of discriminating RVs from decoys. Some of these "active discrimination" schemes are complex and expensive and might in turn be susceptible to offensive spoofing. A third aid to discrimination is the boost-phase defensive layer itself, which might constrain the number and type of penetration aids the offense could mount on each booster in addition to reducing the total number of objects approaching the midcourse tier. Fourth, extensive use of space-based sensors would allow the defense to observe penetration aids throughout their flight (including during deployment from the bus) rather than just as they approach the United States. It remains unclear whether these techniques will be worth the costs and new countermeasures they would bring to the defense.

Section 7
A HYPOTHETICAL SYSTEM ARCHITECTURE

Most analysts of boost-phase BMD assume that midcourse and terminal BMDs will augment the boost-phase layer. This section assembles a hypothetical layered defense system *in toto*. This system is *purely illustrative*, taking current BMD concepts at their face value and conveying a concrete image of the defensive architectures analysts apparently have in mind when they speak of nationwide defense. Obviously there are many choices for such a "strawman" system. The particular system described below was chosen for its illustrative value and not because it represents some "most plausible" alternative. It would be meaningless to suggest a "front runner" in the present state of study and technology development. Rather, the purpose of this example is to show how the layers interact and to indicate the overall scale of the deployments contemplated, without implying that anything remotely like it ever could or would be built.

A defense with several layers presents the offensive planner with some of the variety of problems that afflicts the BMD designer, who never knows in advance which attack tactic or countermeasure the offense will choose and must include responses to all of them in the system design. Layered defense forces the offense not only to develop responses to all the layers, but to develop responses that can be accomplished simultaneously. Thus, for example, the method chosen to avoid boost-phase intercept must not prevent deployment of lightweight midcourse decoys. The synergistic effect of the several layers obviously works strongly in the defense's favor.

Nonetheless, one must compare the performance of a three-tiered defense to the performance of a two-tiered defense of the same cost. Thus it should be no surprise if a $200 billion system with boost (and possibly even post-boost), midcourse, and terminal layers performs better than a $50 billion system with no boost phase layer. The correct questions are whether the additional $150 billion is worth the extra performance, and whether spending the $150 billion on more terminal and midcourse defense would in fact be a better investment.

Occasionally one sees a simplified leakage calculus applied to layered defense. The calculus assigns a "leakage" of, say, 25 percent (0.25) to the boost phase layer, 15 percent to the midcourse layer, and 10 percent to the reentry layer, deducing an "overall leakage" of 0.4 percent on the basis of the equation $(0.25) \times (0.15) \times (0.10) = 0.004$. Though the term leakage can be defined so that this calculus holds, the result actually bears little relation to the number of targets preserved by the defense. For one thing, a given defensive layer does not have an associated leakage *fraction* independent of attack size: the leakage fraction for each layer usually increases with attack size, most obviously (but not only) when the defensive arsenal becomes saturated. Second, the performance levels of the individual layers are not independent. For example, if the midcourse layer's interceptor arsenal is sized to handle only 25 percent of the attack, and the boost-phase layer works poorly and in fact allows 50 percent of the attack through, the midcourse layer obviously cannot display the same fractional efficiency against the attack of double the expected intensity. Conversely, improvements in one layer might improve performance of another: effective boost-phase or midcourse layers might force the offense to abandon the highly structured "laydowns" of RVs in space and time that limit a terminal layer's effectiveness. Third, the raw number or fraction of leaking RVs does not indicate the number or fraction of targets destroyed because of the tactics of preferential offense and defense. For these reasons, the leakage calculus is not a helpful way to encapsulate layered defense performance.

7.1 SYSTEM DESCRIPTION

The system design described below takes literally the goal of comprehensive nationwide defense. It seeks the capability (at least on paper) to engage all attacking Soviet missiles, whether targeted at cities, U.S. silos, or other military installations. Clearly the precise numbers and kinds of components in this description can be adjusted to suit any set of assumptions. The point of this description is merely to convey the flavor of these massive architectures. Most assumptions are favorable to the defense.

Suppose that at some time in the future the Soviet ICBM arsenal still consists of 1,400 boosters, as it does today. For simplicity, suppose further that each booster is an MX-sized solid propellant missile carrying 10 RVs and that all silos are located in one large region of the U.S.S.R. The boosters are not specially shielded against lasers, but some care in their design has given them an effective hardness of 10 kJ/cm^2, and they are further spun during ascent. Each booster carries a small number of decoys, but their small number is offset by the decoys' high fidelity. Each RV is accompanied by 9 lightweight infrared replicas and 1 high altitude reentry decoy. (This is a very modest penetration aid loading. One can assume larger numbers with perhaps poorer fidelity, chaff and aerosols, etc.)

The hypothetical U.S. defense system comprises both HF chemical laser battle stations and x-ray laser battle stations for boost-phase intercept, land-based midcourse interceptors carrying LWIR homing vehicles (the so-called "Overlay"), and land-based high-endoatmospheric homing interceptors with non-nuclear warheads for reentry intercept.

Table 7.1.—Hypothetical Future U.S. Defense Designed for Nationwide Protection Against Hypothetical Future Soviet Offense

U.S. Defense	Soviet Offense
5 warning satellites	1,400 MX-like ICBMs deployed in one region
160 HF laser satellites	10 RVs per ICBM
160 laser radars	9 midcourse decoys per RV
900 x-ray laser satellites	1 reentry decoy per RV
900 MWIR trackers	
28,000 midcourse intercept vehicles and boosters	
20 LWIR satellites	
75 radars	
140,000 terminal non-nuclear interceptors	
25 aircraft with LWIR sensors	

SOURCE: Author.

The HF chemical laser system resembles that described in Section 3.1, except that it has only five 20 MW lasers at each position in the 32-position constellation, for a worldwide total of 160. At a range of 2 Mm, a laser must dwell on each spinning booster for 5 seconds, so each laser at this range can handle 30 simultaneously launched boosters if defense begins 30 sec into the 180 sec boost phase of an MX-like booster. The five lasers overhead the Soviet silos at any one time can therefore only handle 150 of the 1,400 Soviet ICBMs. For small Soviet attacks, however, this non-nuclear boost-phase layer suffices.

For a large-scale Soviet attack, the United States deploys in addition a nuclear boost-phase system of x-ray lasers. A "perfect" laser with characteristics such as those derived in Section 3.3 can intercept ideally about 50 boosters at 4 Mm range. Therefore 28 lasers need to be in position over the Soviet silos at any time to handle a massive launch, giving a worldwide total of 900 (absentee ratio 32).

Warning for the boost-phase system is provided by MWIR warning satellites in synchronous or supersynchronous orbits. Also, each of the 160 HF laser battle stations has an MWIR telescope with 4 m mirror and an ultraviolet or visible ladar with 2 m mirror for pointing. Each x-ray laser is accompanied by an MWIR telescope tracker with 1 m mirror.

The 1,400 Soviet boosters carry 14,000 RVs, 126,000 midcourse decoys, and 14,000 reentry decoys. The United States assumes that only 10 percent of the boosters will survive the boost phase defense, so the midcourse tier needs to face 1,400 RVs and 12,600 midcourse decoys. The midcourse interceptors are given extremely long range, so only two bases are needed to cover the entire United States. However, each base must be prepared to absorb the entire attack, since the Soviets could target one half of the country more heavily than the other. There-

fore the United States needs 14,000 midcourse interceptors at each base, for a total of 28,000 interceptors. A constellation of 20 satellites with large LWIR sensors provide long-range acquisition and target assignment to these interceptors.

The United States next estimates that 90 percent of the RVs that enter the midcourse layer will be successfully intercepted. The terminal defense must handle 140 RVs plus 140 reentry decoys.[1] The reentry decoys are, by assumption, completely faithful in mimicking the signatures of RVs as seen by ground-based radars and aircraft-borne infrared sensors during early reentry—large decoy numbers have been sacrificed for this high fidelity. If the U.S. defense takes literally its charge of nationwide defense, it must be prepared to make 280 intercepts anywhere in the country.

[1]The number of reentry decoys the terminal system must face actually depends on whether the decoys fool the midcourse as well as the terminal system's sensors and on whether the terminal and midcourse layers cooperate in discrimination. Suppose first that the reentry decoys look like RVs (and therefore also like midcourse decoys) to the midcourse layer's sensor. Then the midcourse layer will intercept 90 percent of them (more midcourse interceptors must be bought to do this). If, on the other hand, the midcourse layer correctly identifies the reentry decoys as non-lethal objects, it might (a) not intercept them, requiring the terminal layer to plan to face 140 RVs plus 1400 reentry decoys, increasing enormously the required arsenal of terminal interceptors; (b) intercept them, in which case a reentry decoy is a perfect midcourse decoy, making possible a new threat—large numbers of midcourse decoys that look like reentry decoys rather than RVs; (c) radio the information, object-by-object, to the terminal defense fields.

Each terminal defense site consists of a phased-array radar and a number of high altitude non-nuclear interceptors. Additional target acquisition support is provided by a fleet of aircraft patrolling the U.S. periphery, carrying LWIR sensors. Each radar has a radius of action of over 200 km, so 75 or so cover the entire United States. However, an interceptor only covers an area about 50 km in radius. Since the area of the United States is about 8 million square km, over 1,000 interceptor sites would be needed for nationwide coverage. Should the defense have to reckon with intensive Soviet attack on some regions and no attack on others? Clearly, yes. But equipping each interceptor site to handle all 280 objects passing through the first two layers would require buying 280,000 interceptors! The defense would need to buy this many interceptors if it wanted to claim the literal capability to engage *all* Soviet RVs, *no matter* where they landed. Suppose, then, that the United States hopes for a more evenly distributed Soviet attack and deploys just half of the arsenal needed for complete coverage—140 interceptors per region. One radar might not suffice to handle all the RV traffic in its sector if the Soviets attack some sectors preferentially, but the United States nonetheless buys just 75 radars. Five aircraft on patrol at all times requires a backup fleet totalling perhaps 25.

Table 7.1 summarizes the offensive and defensive deployments.

7.2 ASSESSMENT

It is obviously not possible to assess the performance of a system, such as the hypothetical layered defense described above, whose components are not (and in many cases cannot be) designed today, much less assembled in an overall architecture. It is nonetheless worth sketching, in the illustrative spirit of this section, the issues that would require analysis if anything resembling Table 7.1 were ever proposed for deployment.

The first issue concerns the cost of the improvements to the system needed to offset growth in the Soviet ICBM arsenal—that is, the cost exchange ratio. The number of defensive weapons is proportional to the number of Soviet ICBMs. If the Soviets were to double the size of their ICBM arsenal, the United States would need to double the number of its x-ray lasers and interceptor missiles. (The number of sensors would generally have to increase also, though perhaps not in proportion to the Soviet buildup. The number of HF lasers could remain the same if the United States continued to intend to use this nonnuclear boost-phase layer to engage only Soviet attacks of 150 boosters or less.) Comparison of the two columns of Table 7.1 indicates that an arms race of Soviet offense and U.S. defense seems certain to favor the Soviet side greatly.

A second issue concerns the huge inventories of midcourse and reentry interceptors needed for nationwide defense. The arsenal of reentry interceptors shown in Table 7.1 is in fact only half the size needed for literally complete nationwide coverage, as remarked above. The cause of these large interceptor inventories—besides the obvious presence of decoys—is twofold: first, the low leakage sought by the defense precludes preferential defense, the tactic that makes silo defense so much more economical; and second, the limited coverage of each interceptor battery makes preferential *offense* possible for the attacker. The goal of nationwide low-leakage defense therefore forces the BMD system to forfeit the two sources of leverage that have historically impelled BMD towards the technically modest mission of defending compact silo deployments to relatively low survival levels.

Soviet countermeasures—besides straightforward buildup of ICBMs—is a third issue. The particular boost-phase layers described above are susceptible in varying degrees to all of the countermeasures described in Section 5, and the midcourse and reentry layers to their respective sets of countermeasures.

Defensive coverage against submarine-launched ballistic missiles (SLBMs) is a fourth issue. The boost-phase layers can intercept SLBMs launched from all points on the globe. Though the average range from laser satellite to booster is larger at equatorial and polar latitudes than at the mid-latitudes where Soviet ICBMs are located, the number of SLBMs that could be launched in a short time from each ocean area is also much smaller than the huge number of ICBMs that could lift off simultaneously from the U.S.S.R. Even the chemical laser deployment alone might suffice for boost-phase coverage of SLBMs. The midcourse and reentry layers, however, would in general not perform as well against SLBMs as against ICBMs. SLBM trajectories present bad viewing angles to the midcourse layer's LWIR sensors, and the short timeline limits interceptor coverage. The reentry layer would need to be augmented with more airborne sensors and more radars (or radar faces) to cover attack from the ocean. In general, then, a layered system optimized for ICBM defense could not necessarily handle SLBMs as well.

Section 8
DEFENSIVE GOALS I: THE PERFECT DEFENSE

No assessment of whether a defensive system "works" or not is meaningful without a clear and direct statement of the goal of the deployment. Though there has been much discussion of the feasibility of boost-phase BMD, proponents and skeptics alike frequently leave unstated the standards against which they are judging the technical prospects. A "successful" BMD deployment could be defined as anything from a truly impenetrable shield, to a silo defense that merely costs less to build than it costs the Soviets to overcome, to a tangled deployment that just "creates uncertainty" for the attacker.

The most ambitious conceivable goal for BMD would be to take at literal face value the words of President Reagan in his so-called "Star Wars" speech of March 23, 1983, when he called for development of a defense capable of making nuclear weapons "impotent and obsolete."[1] It is not clear that the President intended his words to be taken literally, nor that the Administration or anyone else is suggesting the United States seek a truly perfect or near-perfect defense.[2] Nonetheless, so much writing and debate focuses on this prospect, and its importance is so great, that it is taken up in this section. Section 9 treats the many other possible goals for less-than-perfect defenses.

There is some confusion in the literature about the use of the term "mutual assured destruction" (MAD) in connection with the notion of perfect defense. In common strategic parlance, MAD refers to the *technological circumstance* of mutual vulnerability to catastrophic damage from nuclear weapons, not to a *chosen policy* to promote such vulnerability. There is a strategic school of thought that advocates a policy usually called "minimum deterrence," maintaining that the capability for assured destruction of Soviet society is the *only* requirement of U.S. strategic forces. However, many experts believe that effective deterrence and other national security objectives require nuclear forces capable of many other tasks than assured destruction. This section addresses itself to the question of whether MAD is an avoidable technological circumstance, *not* to whether minimum deterrence is a prudent strategic policy.

A sensible start at judging the prospect for near-perfect defense must involve two steps: first, an exact statement of what perfect defense means in the context of attack on society with nuclear weapons; second, some way of gauging the likelihood of success when the technological future cannot be accurately predicted.

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[1] *Weekly Compilation of Presidential Documents*, Vol. 19, No. 12, March 28, 1983, pp. 447-448. The text of the relevant part of the speech is reprinted as Appendix A.

[2] Defense Secretary Caspar Weinberger appeared to confirm a literal interpretation in a March 27 interview on NBC's *Meet the Press*, when he said (as reported in the *Baltimore Sun*, March 28, 1983, p. 1):

> The defensive systems the President is talking about are not designed to be partial. What we want to try to get is a system which will develop a defense [sic] that is thoroughly reliable and total. I don't see any reason why that can't be done.

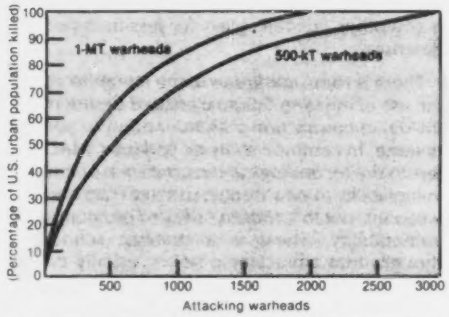
Later, the Defense Department stated that the purpose of the President's initiative was not to save lives, but to deter war. Responding to the "Congressional Findings" section of the proposed "People Protection Act" (H.R. 3073, 98th Congress, 1st session) which stated, "The President has called for changes in United States strategic policy that seek to save lives in time of war," Defense Department General Counsel William H. Taft IV wrote:

> It is clear that portions of the "Congressional findings" section [of H.R. 3073] vary from the purpose of the President's initiative. First, and most importantly, the purpose of the President's initiative is to strengthen our ability to deter war by, as the President has said, " . . . rendering [ballistic missiles] impotent and obsolete." In short, the purpose of the Administration's policy is to reduce the likelihood of war. The finding [of H.R. 3073] that the purpose is to "save lives in time of war" departs from our goal of deterring war.

Dr. Charles Townes, a frequent adviser to Secretary of Defense Weinberger and leader of two DOD task forces studying basing modes for the MX missile, said that a perfect defense proposal is "quite impractical. There is no technical solution to safeguarding mankind from nuclear explosives." (*New York Times*, April 11, 1983, p. 14).

8.1 NUCLEAR ATTACK ON SOCIETY

Figure 8.1.—The Effect of Attack Size on the Extent of Prompt Fatalities in U.S. Urban Areas



Note: Aimpoints chosen to maximize prompt human fatalities. U.S. urban population is estimated to be 131 million, as in the 1970 census.

SOURCE: Arms Control and Disarmament Agency, *U.S. Urban Population Vulnerability* (ACDA, 1979), quoted in Arthur M. Katz, *Life After Nuclear War: The Economic and Social Impacts of Nuclear Attacks on the U.S.* (Ballinger, 1982). Adapted from Ashton Carter and David N. Schwartz, eds., *Ballistic Missile Defense* (The Brookings Institution, 1984), p. 188.

Suppose one wants to take literally the goal of removing from the hands of the Soviet Union the ability to do socially mortal damage to the United States with nuclear weapons, so that the Soviet Union no longer possesses the elemental capability of assured destruction.) What does this mean?

Figure 8.1 shows how the percent of the U.S. urban population (about 130 million people in the 1970 census) killed promptly increases with the number of Soviet warheads detonating over U.S. cities. No such curve of the effects of nuclear attacks on cities should be taken as anything but suggestive: uncertainties are very great in such estimates, and no attempt has been made to reflect long-term and indirect effects of the detonations.[3] The curve also accounts only for fatalities, not for the many additional people injured. If one wishes to account for the possibility of civil defense evacuation, then the curve should be taken to represent not the number of people killed, but the number of people whose homes, businesses, historic monuments, schools, and places of worship have been destroyed.

No one supposes that the Soviet Union actually chooses aimpoints for its nuclear weapons with the goal of maximizing human fatalities, as has been done in preparing Figure 8.1. If the United States possessed a defense capable of intercepting all but a few of the 8,000 to 10,000 Soviet nuclear warheads, however, the Soviet Union might retarget its forces to wreak the most destruction possible with its few penetrating warheads. At any rate, any defense promising U.S. society genuine immunity from nuclear attack must reckon with Soviet determination to keep its arsenal from being "rendered impotent," and therefore with targeting plans contrived to do the most damage to the fabric of U.S. society.

Where on the curve of Figure 8.1—after how many detonations—does one locate the boundaries of "assured destruction," "assured survival," "impotent and obsolete," and similar phrases? Clearly there is no analytical prescription for these boundaries: they are the subject of a broader human judgment. 500 half-megaton warheads kill half the urban population, injure most of the rest, and totally destroy all American cities and large towns. Just 5 megatons, about one two-thousandth of the Soviet arsenal, detonated over the 10 largest U.S. cities could kill several million people and wound over 10 million more.

For the sake of discussion, we shall use 100 megatons—about 1 percent of the Soviet Union's arsenal and 1.5 percent of its ICBM force—as the level of penetration for which a defense would

[3]For discussion of some of the effects of nuclear weapons on population and cities, see: U.S. Arms Control and Disarmament Agency, *An Analysis of Civil Defense in Nuclear War* (ACDA, 1978); OTA, *The Effects of Nuclear War* (GPO, 1979); ACDA, *The Effects of Nuclear War* (ACDA, 1979); "Economic and Social Consequences of Nuclear Attacks on the United States," prepared for the Joint Committee on Defense Production, 96 Cong. 1 sess., 1979; J. Carson Mark, "Global Consequences of Nuclear Weaponry," *Annual Review of Nuclear Science*, Vol. 26 (1976), pp. 51-87; National Research Council, *Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations* (National Academy of Sciences, 1975).

be judged "near-perfect." This definition is obviously very generous to the notion of perfect defense, since most people would presumably not regard 100 megatons of explosive force as "impotent and obsolete." Still, it is a definite reference for assessment.

8.2 THE PROSPECTS FOR A PERFECT DEFENSE

There is not and cannot be any "proof" that unknown future technologies will not provide near-perfect defensive protection of U.S. society against Soviet ICBMs. The question that needs to be answered is whether the prospects for near-perfect defense are so remote that such a notion has no place in reasonable public expectations or national policy. It is, after all, not provable that by the next century the United States and U.S.S.R. will not have patched up their political differences and have no need to target one another with nuclear weapons. The issue of the perfect defense is unavoidably one of technical judgment rather than of airtight proof.

Four misapprehensions seem common among non-technical people addressing the prospects for perfect defense.

The first misapprehension is to equate successful technology development of individual *devices*—lasers, power sources, mirrors, aiming and pointing mechanisms—with achievement of an efficient and robust defensive *system*. Millionfold increase in the brightness of some directed-energy device is a necessary, but is far from a sufficient, condition for successful defense. In the early 1960's, intercept of RVs with nuclear-tipped interceptor missiles was demonstrated—"a bullet could hit a bullet"—but 20 years later systems incorporating this "kill mechanism" are still considered relatively inefficient. In general, skeptics about the future of space-based directed-energy BMD do not confine their doubts to, or even emphasize, unforeseen problems in developing the individual components.

A second misappprehension arises in attempts to equate BMD development to past technological achievements, such as the Manhattan project's atomic bomb or the Apollo moon landings.[4] The technically minded will recognize a vital difference between working around the constraints imposed by nature, which are predictable and unchanging, and competing with a hostile intelligence bent on sabotaging the enterprise. A dynamic opponent makes of BMD, first, a more difficult design problem, since the offense constructs the worst possible barriers to successful defense; and second, not one problem but many problems that need to be sidestepped simultaneously in the design, since the designer cannot be certain which tactics the offense will use.

A third misapprehension concerns the prospect for a "technological breakthrough" that would dispel all difficulties. Such breakthroughs are not impossible, but their mere possibility does not help in judging the prospects for the perfect defense. For one thing, an isolated technological breakthrough creating a new defensive component would not necessarily alleviate the system issues—vulnerability, dependability, susceptibility to countermeasures, cost—that determine overall effectiveness. Second, one can just as easily imagine offensive "breakthroughs," sometimes involving the same technologies. Thus the x-ray laser, if it matures, might turn out to have been

[4]Defense Secretary Caspar Weinberger has written (*Air Force Magazine*, Nov. 1983):

> The nay-sayers have already proclaimed that we will never have such technology, or that we should never try to acquire it. Their arguments are hardly new . . . In 1945 President Truman's Chief of Staff, Adm. William Leahy, said of the atomic bomb: "That's the biggest fool thing we've ever done. The bomb will never go off, and I speak as an expert in explosives." In 1946 Dr. Vannevar Bush, Director of the Office of Scientific Research and Development said of intercontinental ballistic missiles, "I say technically I don't think anybody in the world knows how to do such a thing, and I feel confident it will not be done for a long time to come." These critics were proved wrong; what is more, they were proved wrong quickly.

better termed a breakthrough in strategic offense than a breakthrough in strategic defense.

A fourth misapprehension concerns the confidence with which predictions could be made about the performance of a complex system once in place. The "performance" of a system, as quoted in analyses, is the most likely outcome of an engagement of offense versus defense. Other outcomes, though less likely, might still be possible. Computing the relative likelihoods of *all* possible outcomes would be difficult even if one could quantify all technical uncertainties and statistical variances. Still, there would remain a residue of uncertainty about the performance of a system that had never been tested once in realistic wartime conditions, much less in a statistically significant ensemble of all-out nuclear wars. The defense would also have no chance to learn and adapt. In World War II, by contrast, air defense crews learned in raid after raid to inflict losses of several percent in attacking bombers. The only reason these modest losses assumed strategic significance was that they accumulated over many raids. Of course, the same uncertainties plague the offense as plague the defense. In general, the offense would tend to overestimate the defense's capability. This natural tendency toward "offense conservatism" is probably vitally important to the psychological and deterrent value of BMD as it is applied to less-than-perfect goals. For the perfect defense goal (as defined above), however, it would seem that the uncertainty weighs heaviest on the defense. To the reckless, non-conservative defense, a wrong estimate of defense performance spells the difference between safety and socially mortal damage (or between deterrence and war). The reckless offense, on the other hand, is presumed desperate enough to try to inflict such damage on its enemy and willing to accept the consequences: it stands to lose little if its estimates are wrong and the defense *does* work perfectly after all.

With these misapprehensions out of the way, and recognizing clearly that there can be no question of "proof," it would seem that four major factors conspire to make extremely remote the prospect that directed-energy BMD (in concert with other layers if necessary) will succeed in reducing the vulnerability of U.S. population and society to the neighborhood of 100 megatons or less.

1. **Near-perfect defense of society is much harder and more expensive than partial defense of military targets.** That is, the marginal cost exchange is much higher for near-perfect defense than for partial defense (see also Fig. 5.2). There are two reasons behind this well-known statement.

The first reason is illustrated schematically in Figure 8.2. In going from partial silo defense to perfect city defense, the BMD loses the leverage of preferential defense. Additionally, the offense gains the leverage of preferential offense against the terminal and midcourse layers with their limited geographic coverage, although *not* against the boost-phase layer. In Figure 8.2(a), the defense aims to save only 10 percent of the ICBM force, or one silo. Assuming perfect interceptors and adopting the tactic of adaptive preferential defense (using all its interceptors to save just one silo chosen randomly from the ten at the moment of attack), the defense concludes it needs to prepare to make one only intercept to counter the offense's 10 RVs. In Figure 8.2(b), the offense can focus all 10 of its RVs on any one of ten cities. The defense must prepare to make 10 intercepts for each city, buying a total of 100 interceptors, if it wants to try to save all the cities. If the Soviets double their RV arsenal, the United States must buy just one interceptor to satisfy the defense goal of Figure 8.2(a), but the United States must buy 100 interceptors to satisfy the defense goal of Figure 8.2(b). The cost exchange ratio is thus 100 times worse for the city defense, even though it uses the same technology as the silo defense.

The second reason why a near-perfect defensive goal shifts the cost burden in favor of the offense is that the offense can turn all its resources to improving or replacing just a portion of its ICBMs to sidestep the defense. The Soviet Union could therefore harden just 1 percent of its boosters, perhaps concealing exactly which ones were hardened. Moreover, it could deploy a few fast-burn boosters immune to x-ray lasers and neutral particle beams; build a few different ASAT de-

Figure 8.2

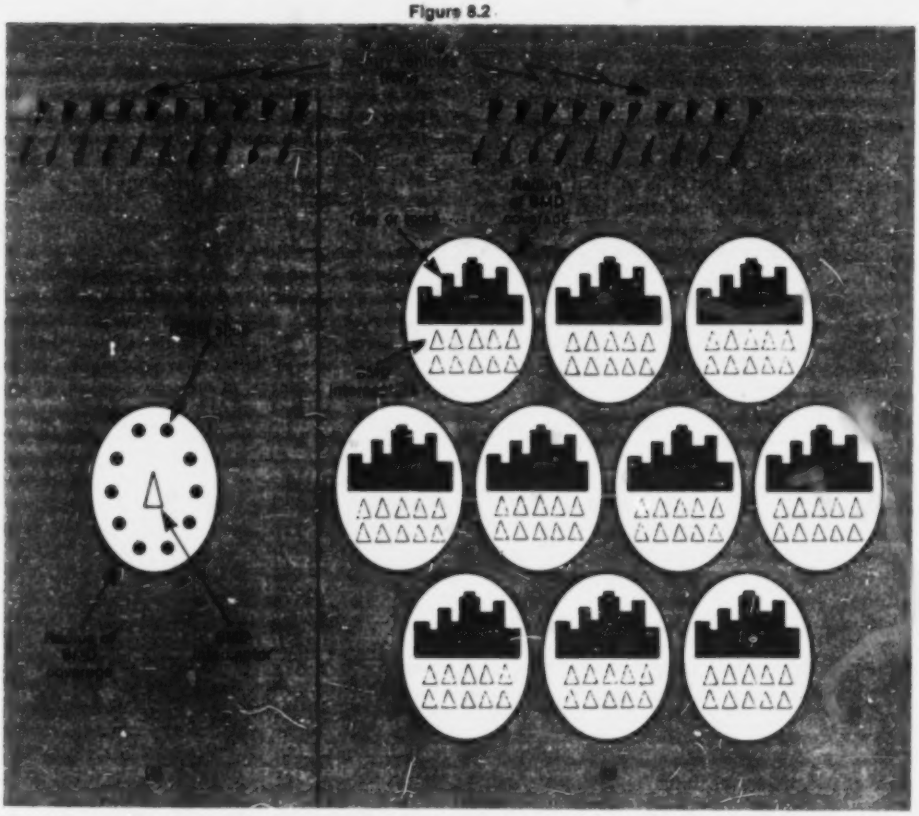


Figure 8.2. The cost to a U.S. reentry BMD to compete with increases in the size of the Soviet arsenal (the "marginal cost exchange") is much greater for near-perfect city defense (b) than for partial silo defense (a). In going from (a) to (b), the U.S. loses the leverage of preferential defense and the Soviet Union gains the leverage of preferential offense.

vices; and so on. More costly countermeasures are available to the offense if the countermeasures need only be implemented on a small scale rather than throughout the ICBM force. The offense can "experiment" with a number of different tactics with different portions of its force. The defense's costs also grow much larger if it must plan to face a *variety* of offensive countermeasures. In short, the defense must be able to stop all kinds of attack, but the offense only has to find one way to get through.

2. **For every defense concept proposed or imagined, including all of the so-called "Star Wars" concepts, a countermeasure has already been identified.** These countermeasures were enumerated in Section 5 and will not be repeated here. Three further generalizations about these countermeasures reinforce a poor prognosis for cost-effective near-perfect defense: 1) In general, the countermeasures could be implemented with today's technology, whereas the defense itself could not; 2) In general, the costs of the coun-

termeasures can be estimated and shown to be relatively low, whereas the costs of the defense are unknown but seem likely to be high; 3) In general, the future technologies presupposed as part of the defense concept would also be potent weapons for attacking the defense.

3. **The Soviet Union does not configure its nuclear missile forces today to maximize damage to U.S. society and population, but it could do so if faced with near-perfect U.S. defenses.** Targeting plans could focus exclusively on damaging cities. High missile accuracy would be unnecessary, lowering offense costs. Nuclear weapons could be designed to maximize harmful fallout. ICBM survivability measures—silos, racetracks, densepacks, etc.—would be unnecessary to a side striking first or possessing its own defense effective at saving many missiles (but not *all* cities); thus basing costs could be diverted to the city-kill goal. Presumably the Soviet Union would take these and any other measures necessary to prevent itself from being effectively disarmed by a U.S. defense, since otherwise it would be at its enemy's mercy.

4. **BMD by itself will not protect U.S. society from other methods of delivering nuclear weapons to U.S. soil or from other weapons of mass destruction.** Bombers and cruise missiles (and to a significant extent SLBMs and IRBMs) present very different defensive problems than ICBMs. Today the technical problems of air defense are no better resolved than the technical problems of BMD. Novel future offensive delivery vehicles can only be conjectured along with the future defense technologies discussed in this Paper. A desperate Soviet Union could introduce nuclear weapons into the United States on commercial airliners, ships, packing crates, diplomatic pouch, etc. Other methods of mass destruction or terrorism would be feasible for the U.S.S.R., including sabotage of dams or nuclear power plants, bacteriological attack, contaminating water, producting tidal waves with near-coastal underwater detonations, and so on.

Section 9

DEFENSIVE GOALS II: LESS-THAN-PERFECT DEFENSE

A host of less grandiose goals than perfect or near-perfect defense assume importance in certain theories about the workings of nuclear deterrence and the requirements of U.S. security. Thoughtful observers debate not just the feasibility of achieving these goals but the validity and importance of the goals as well. The urgency one attaches to these goals determines the costs, risks, and harmful side effects one is willing to incur to fulfill them. Assessing the wisdom of less-than-perfect defense thus involves a complex and subjective balancing of goals and risks, in which purely technical issues sometimes take a back seat. In discussion of perfect defense, by contrast, technical assessment is paramount. This section therefore calls up many issues of nuclear policy not subsumed under the title of this Background Paper, and no pretense is made here to complete treatment.[1]

Though various strategic goals for BMD can be distinguished in principle, in practice it might not be clear or agreed among all parties in the United States what the purpose of a proposed deployment actually was. Interpretations by the Soviet Union and other foreign nations of U.S. goals might be quite different yet.

[1]For a more complete treatment of the entire subject of BMD, see Ashton B. Carter and David N. Schwartz, ed., *Ballistic Missile Defense* (The Brookings Institution, 1984).

Those familiar with BMD design and assessment will recognize that stating a general *strategic* goal is not enough: the *technical* specifications are essential. For instance, it makes an enormous difference in silo defense whether the defense seeks to charge the offense a price of five RVs (or half a booster) or 10 RVs (one booster) per silo.

For goals requiring very modest performance, terminal and midcourse defenses might suffice. Since no one knows whether boost phase defenses, when better defined, will surpass or even equal traditional defenses in terms of leakage and cost exchange, there is no point in turning to exotic technologies to satisfy modest goals. Virtually all observers agree, on the other hand, that terminal and midcourse systems are unequal to the more demanding goals; for these goals one is forced to direct one's hopes to the promise of future technologies.

This section sketches various goals for less-than-perfect defenses and the strategic thinking that attaches importance to them. It then points out a number of side effects against which fulfillment of these goals needs to be balanced. This short section is no substitute for a comprehensive assessment of the pros and cons of BMD.

9.1 GOALS FOR LESS-THAN-PERFECT DEFENSE

1. **Strengthen deterrence by preventing preemptive destruction of retaliatory forces.** It is widely recognized that the Soviet Union will soon have, if it does not already, the combination of yields, numbers, and accuracy in its ICBM forces to destroy most U.S. Minuteman ICBMs in their silos. It is also widely agreed that vulnerable nuclear forces create unwanted temptations for both sides to strike first if war seems likely. The long and anguished search for survivable basing modes for the U.S. MX (Peacekeeper) ICBM has to date turned up no clear favorites when survivability is balanced against cost, technical risk, strategic effects, and environmental impacts.[2] BMD would substitute for or complement these other basing modes. By shooting down a fraction of the opponent's missiles, BMD would in effect "de-MIRV" ICBM forces.

Of course, turning to BMD to ease ICBM vulnerability is not without problems. One problem is the prospect of a compensating Soviet BMD.

[2]*MX Missile Basing*, Office of Technology Assessment, U.S. Congress, September 1981.

MX is presumably being bought and made survivable in the first place so that the U.S. can absorb a Soviet strike and retaliate with its ICBMs (in addition to its bombers and submarines) against Soviet targets. But modification or termination of the ABM Treaty to permit a U.S. defense would permit a Soviet defense as well. The surviving U.S. ICBMs guaranteed by the U.S. BMD might still not result in retaliatory damage to Soviet targets if these targets are defended by Soviet BMD. The U.S. BMD deployment, all bought and paid for, might therefore have been cancelled out by a Soviet counter-deployment.

Other elements of the U.S. retaliatory force comprise command and control links, bomber alert bases, and in-port submarines. Bomber bases, sub ports, and fixed command and control facilities are the worst type of target base for BMD to try to defend—a small number of high-value, soft, and interdependent targets. The important remaining category of mobile command and control facilities, on the other hand, does not easily lend itself to active defense with BMD.

2. **Strengthen deterrence by preventing the use of nuclear weapons as decisive military tools for high-confidence "limited" strikes on conventional forces.** This goal is associated with so-called "warfighting" strategies for nuclear weapons. According to analysts who hold this view, today's "offense dominated" world creates dangerous temptations to resort to nuclear weapons to accomplish militarily well-defined objectives. One can imagine warheads simply being lobbed unopposed into another country in any number or combination. Though surely the effects of these "limited" attacks on nearby communities would not be so well-defined, the effect on the opposing military machine might be truly dramatic, even decisive. This use of nuclear weapons in wartime is possible with today's unopposed offenses with considerable confidence and might therefore be tempting to the combatants. Such temptations threaten nuclear deterrence and should be eliminated. The goal of a comprehensive defense would be to make such limited attacks infeasible, or at least to complicate the offense's estimations of success to such a degree that it would not attempt an "experiment."[3] Analysts who favor this approach usually maintain that Soviet military doctrine inclines the Soviets towards a view of nuclear weapons as military tools to a far greater degree than is common in U.S. thinking.[4]

To take an explicit example (in this case of Soviet failure to deter the U.S.) of a "warfighting" scenario (chosen randomly from a great many possibilities), suppose NATO were at war with the Warsaw Pact, and the Soviets were resupplying their ground offensive through just 10 or so rail trunks from the Soviet Union through eastern Europe. Just 10 well-placed nuclear weapons (according to a hypothetical analyst considering this type of scenario) would cut off a large fraction of supplies coming to the front, slowing the Pact offensive and giving NATO vitally needed time to marshall its defenses. Wouldn't the United States be sorely tempted to use just a few ICBMs for this decisive intervention in the course of the war?

Analysts who recommend attention to warfighting scenarios and doctrines are surely aware of the profound difference between conventional and nuclear weapons, but they maintain that the threat of punishment through retaliation upon cities is not an effective deterrent in such scenarios. Wouldn't it be preferable if these scenarios were simply closed off by defensive technology?

Critics of this BMD goal object both to the warfighters' emphasis upon the risk of this type of scenario and to the assumption that defense would materially diminish that risk. In their view, myriad detailed chinks in the armor of deterrence can always be found, with or without defense, and worrying about them represents a loss of

[3]Presidential Science Adviser George A. Keyworth, II has stated (interview with *U.S. News and World Report*, April 11, 1983, p. 24):

> "The objective is to have a system that would convince an adversary that an offensive attack will not be successful. It has to be a very effective system, but it would not have to be perfect to convince a potential adversary that his attack would fail."

Dr. Robert Cooper, director of the Defense Advanced Research Projects Agency has also stated this view (*The New York Times*, Nov. 5, 1983, p. 32): "Even if only 50 percent of all incoming missiles were stopped, the Soviets could then have no confidence in the success of a first strike, and war would be more remote."

[4]*Ballistic Missile Defense*, op. cit., Chapter 5.

perspective on the basic difference between nuclear and conventional instruments of war. Besides, they say, suppose the effect of the Soviet BMD is to force the United States to attack each rail line with ten weapons instead of one to assure penetration: Is there truly a psychological divide between using 10 and 100 nuclear weapons, once the divide between 0 and 10 has been crossed? Third, would NATO not be adequately deterred by the prospect of Soviet retaliation with 10 of its nuclear weapons against 10 vital NATO targets? Last, suppose NATO used 10 cruise missiles, against which the BMD was powerless, instead of 10 ICBM RVs?

The persuasiveness of this second goal for less-than-perfect BMDs therefore depends on one's views of the roles and risks of nuclear weapons—views that are fundamental and deeply held. This goal is therefore one of the most controversial of all.

3. **Save lives.**[5] Another goal for BMD is purely humanitarian and seeks no military or strategic advantage. If the defense did not interfere too much with Soviet military targeting objectives (enough for the Soviets to try to overcome it), and assuming the Soviets have no explicit aim to inflict human casualties, the United States could expect some reduction in fatalities in a nuclear war even from a modest defense. This reduction would necessarily be limited, since Soviet military objectives include destruction of many targets collocated with population. BMD and civil defense measures would be mutually reinforcing.

Analogous discussion of civil defense has always revealed an inherent tension between the humanitarian objective of defense and a related strategic objective. The strategic objective seeks to reduce fatalities and damage in order to enhance U.S. "flexibility" in a crisis, to allow the United States to "coerce" the U.S.S.R. (or avoid coercion) from a position of reduced vulnerability, or to enhance U.S. ability to persist in its war effort despite receiving a Soviet nuclear strike. The supposed result of the BMD deployment is to allow the U.S. President, in dealing with the Soviet leadership in time of crisis, to be more willing or appear to be more willing to resort to nuclear war because the consequences to the United States are presumed smaller.

The coexistence of the humanitarian and strategic objectives for the analogous case of civil defense is apparent in the literature on civil defense. The Defense Department[6] has argued that the United States should have the same crisis relocation options as the U.S.S.R. for two reasons, one strategic and one humanitarian: 1) "to be able to respond in kind if the Soviet Union attempts to intimidate us in time of crisis by evacuating the population from its cities"; and 2) "to reduce fatalities if an attack on our cities appears imminent." Prominent scientists arguing for civil defense have also maintained that, "A nation's civil defense preparedness may determine the balance of power in some future nuclear crisis. . . . In our opinion, we must strive for an approximately equal casualty rate".[7] More recently, the High Frontier Study urging strengthened U.S. strategic defenses stated: "The protection of our citizens must be prime, but civil defense . . . would reduce the possibility that the United States could be coerced in a time of crisis".[8]

In practice, therefore, the humanitarian and strategic objectives are likely to be difficult to disentangle. Unlike the humanitarian objective, the strategic objective might stimulate a Soviet effort to put the same number of American lives at risk regardless of the defense. In this way, the Soviet Union could retain the strategic advantage that, by hypothesis, the BMD deprives them of. The issue then becomes the usual one of the cost-exchange ratio measuring the price to the Soviet Union of retaining its "advantage" relative to the price of the U.S. defense.

The Defense Department has stated that saving lives in time of war is not the purpose of President Reagan's BMD initiative.[9]

[5]This discussion borrows from the author's previous work in *Ballistic Missile Defense*, op. cit., Chapter 4.

[6]*Annual Defense Department Report, FY 1976*, p. II-24.

[7]Arthur A. Broyles and Eugene P. Wigner, "Civil Defense in Limited War," *Physics Today*, vol. 29 (April 1976), pp. 45-46.

[8]Daniel O. Graham, *The Non-Nuclear Defense of Cities: The High Frontier Space-Based Defense Against ICBM Attack* (Abt Books, 1983), p. 122.

[9]See footnote 8.2.

4. **Shape the course of the arms competition and arms control.**[10] One version of this goal sees the Soviet tendency to upgrade and proliferate existing ICBM forces as the principal impediment to arms control. By introducing BMD (or even discussing it), according to this view, the United States makes the Soviets unsure about the next step in the arms competition and thus undercuts the momentum of Soviet strategic programs, especially ICBM modernization. Though fast-burning Midgetman boosters might defeat boost-phase defenses, this argument goes, the slow-burning SS-18s and SS-19s will not. BMD might not be able to make all nuclear weapons impotent and obsolete, but it can make large Soviet ICBMs impotent and obsolete—something the U.S. has been trying to do for a decade. Perhaps efficient defenses will "force" the Soviets to emphasize submarines, bombers, and cruise missiles in their strategic arsenal to the same degree the United States does. (One problem with this line of argument is that by the time the defense is in place, present-generation Soviet ICBMs might already be replaced.)

Another line of argument holds that a major BMD initiative strengthens the U.S. negotiating position at START. An aggressive BMD program demonstrates U.S. technological prowess and hints at what the Soviets could face if this prowess were unleashed. It would seem that new BMD initiatives might not coexist easily with the reductions in offensive arsenals proposed by the United States in START, however. Since U.S. BMD is equivalent to attrition of the Soviet ICBM arsenal, any anxieties the Soviets feel at reducing the size of their missile inventories would, logically at least, be enhanced by a simultaneous U.S. BMD buildup. Politically, it would seem unlikely, though certainly not impossible, that a climate favorable to far-reaching offensive arms control would also foster an amicable dismantling of the ABM Treaty.

5. **Respond to Soviet BMD efforts.** Many analysts view with alarm Soviet strategic defense activities, including upgrading of the Moscow ABM, development of a transportable terminal BMD system, construction of a radar in apparent violation of the ABM Treaty, development of defenses against tactical ballistic missiles, incorporation of limited BMD capability in air defenses, and continued attention to other damage-limiting methods (civil defense, air defense, antisubmarine warfare, and countersilo ICBMs). A strong U.S. BMD research and development program might deter the Soviets from breaking out of the ABM Treaty and from continued encroachments on the Treaty's provisions. It is frequently noted that aggressive U.S. research into penetration aids and other methods for countering defenses might be an even more effective way to demonstrate to the Soviets that they would be ill-advised to overturn the ABM Treaty's "freeze" on missile defenses.

6. **Protect against accidental missile launches and attack from other nuclear powers.** These goals have been put forward several times in the past, most notably in the late 1960's when the Johnson Administration proposed the Sentinel ABM system to counter Chinese ICBMs, believed at that time to be fast-emerging. Neither goal figures prominently in today's discussion of BMD in the United States, though defense against Chinese, British, and French missiles could well loom larger in Soviet thinking. Emerging nuclear powers or terrorists would be unlikely to use ICBMs to deliver their small nuclear arsenals to the United States. BMD is therefore of little importance in staving off the threat to U.S. security posed by nuclear proliferation.

[10]Presidential science adviser George A. Keyworth, speech before the Washington chapter of the Armed Forces Communications and Electronics Association, as reported in *Defense Week* (Oct. 17, 1983):

> "Although the strategic defense program's goal would still be eventual deployment of a working system, we shouldn't overlook its potential beneficial impact on arms reduction as its progresses."

Richard DeLauer, Undersecretary of Defense for Research and Engineering, has said that an arms control agreement is needed to prevent the Soviets from overcoming a defensive system: "With unconstrained proliferation [of Soviet missiles], no defensive system will work." (Interview with *The New York Times*, May 18, 1983).

9.2 SIDE EFFECTS OF BMD DEPLOYMENT

The inevitable side effects of a major strategic initiative such as BMD might turn out to match, both in magnitude and in duration, the beneficial effects of satisfying the goal emphasized by the system's purveyors. The public and policymakers would therefore need to assess the net, long-term effect of adding BMD to the strategic equation, and not just the achievement of a certain discrete goal as if by surgical intervention. This section reviews the well-known list of BMD side effects. Many of these effects are detrimental to U.S. security and would need to be balanced against the benefits of fulfilling the modest goals of less-than-perfect defense. In making this assessment, it is impossible to ignore the many unknowns and uncertainties that make it impossible to compare today's world without BMD to a future world with BMD.

1. **First strike versus ragged retaliation.** It is frequently noted that BMD ends up being a better investment for the side that strikes first than for the side that retaliates. Weapon systems that create relative advantages to striking first in a crisis (rather than risking being struck while seeking a peaceful resolution) are defined to be "destabilizing." The side striking first uses its full arsenal in an organized penetration of the other side's defense; the retaliating side can only use its surviving arsenal in a possibly disorganized "ragged retaliation" against a forewarned and fully prepared defense.

Mitigating factors could in certain circumstances soften this classical statement of the destabilizing effect of BMD. First, truly effective defenses might prevent the first striker from destroying a substantial fraction of the other side's retaliatory forces. Second, with proper planning (involving post-attack retargeting and coordinated timing), the retaliating forces might still be able to mount a tailored, efficient strike. Third, there will seemingly always be a *relative* advantage to being the side that strikes first in a nuclear war, with BMD or without BMD; but this calculus of relative advantage is far from being the only factor in deterrence. Other stabilizing factors might be strengthened by BMD, offsetting this destabilizing factor. Thus BMD might also *discourage* temptations to strike first, by threatening to disrupt the attack.

2. **Soviet BMD.** A U.S. BMD deployment would seem very likely to stimulate a Soviet deployment. Even if the Soviets saw no compelling military rationale for following suit, political appearances could prove decisive. A Soviet BMD counter-deployment would obviously blunt U.S. offensive striking power, which the U.S. has been spending a great deal to build up. If the U.S. deployment sought to protect its ICBMs from preemptive destruction in their silos (Goal 1 above), the Soviet BMD might nonetheless nullify the U.S. ICBMs—this time in flight to their targets. Soviet BMD would also introduce a threat to U.S. SLBMs, which are today thought to be virtually immune to Soviet disruption and to be significantly advanced relative to their Soviet counterparts. If the U.S. deployment sought to prevent "limited" strikes by the Soviets Union (Goal 2), the Soviet BMD might in turn preclude a U.S. option to use nuclear weapons selectively and flexibly in support of its NATO allies—an option sometimes seen as central to NATO strategy. Clearly the actual effect of the Soviet BMD counterdeployment would depend upon its technical characteristics and the targets it defended.

3. **Demise of the ABM Treaty.** An arms control treaty obviously cannot serve as its own justification, and presumably virtually everyone would agree to the abandonment of the ABM Treaty the moment it ceased genuinely to serve the national security. In addition to its concrete provisions limiting BMD deployment, however, the ABM Treaty has unavoidably assumed a symbolic political meaning in the United States and, in different forms perhaps, in Europe and the U.S.S.R. The Treaty stands for a decade of arms control and attempts at superpower understanding about nuclear weapons. As a practical matter, it is impossible to overturn the Treaty's technical provisions without calling into question U.S. commitment to the whole fabric of the SALT/START process. This side effect would have to be weighed against the purely military and strategic

benefit (if there were, in fact, a net long-term benefit) of a U.S. BMD deployment.

4. **Allied and Chinese missile forces.** The nuclear missile forces of Britain, France and China are obviously a greater threat to the Soviet Union than to the U.S. Most analysts agree that the existence of these forces enhances U.S. security. But a major BMD initiative sparking widespread Soviet defense would in effect disarm our allies (to a degree depending on the nature of the Soviet deployment).

5. **Accompanying strategic programs.** A number of new weapon systems and strategic programs would be natural, though perhaps not necessary, accompaniments to BMD. On the offensive side, the U.S. would need to develop and deploy penetration aids against the Soviet BMD and improve its bomber and cruise missile forces to reflect added reliance on non-missile delivery vehicles. On the defensive side, the overall category of "strategic defense" comprises, in addition to BMD: nationwide air defenses against Soviet bombers and cruise missiles, defensive coverage against SLBMs, civil defense shelters and evacuation plans, and passive "hardening" of military installations and industrial facilities.

6. **Opportunity Costs.** The initial investment in BMD deployment, the inevitable follow-ons, and any accompanying strategic programs would make a substantial, permanent demand on the defense budget, competing with other nuclear forces and with conventional forces, not to mention with nonmilitary expenditures.

In a more fundamental sense, the transition from a world with a near-total ban on BMD to a world with BMD deployments is probably an irreversible change. Reimposing a defensive "freeze" after a period of unrestrained deployment, much less dismantling defenses and returning to zero, would involve all of the problems that attend upon arms control reductions at START today. Extra caution seems warranted where strategic actions cannot easily be reversed or recalled: the opportunity for a comprehensive ban on missile defense might not arise again.

7. **Bean counting.** Strategists, politicians, and diplomats place considerable emphasis on quantitative measures of the nuclear balance and on "proofs" that "parity" exists. Arms control negotiations also reduce themselves quickly to counting rules. It is unclear whether or how BMD should affect such "bean counting." For each U.S. battle station added to a defensive constellation, are the Soviets to be credited with fewer ICBMs, since the U.S. defense represents potential attrition of the Soviet force? How many Soviet interceptor missiles equals one U.S. laser? Whose estimate of the BMD's likely wartime performance—the defense's or the offense's—governs these counting rules? Experience indicates that these types of questions, however far-fetched and even preposterous they appear in prospect, in the end assume considerable perceived importance.

8. **Asymmetries.** The Soviet BMD deployment that could well follow U.S. deployment might not share the same defensive goal or the same technology, stimulating the usual anxieties about unequal intentions and capabilities. Defensive systems are also complex, leading different analysts to widely different conclusions about the likely wartime performance of the BMD systems on both sides. Moreoever the owner of the BMD, aware of all the system's hidden flaws, might credit it with little capability, whereas the offense planner will tend to give it the benefit of the doubt. Though some hypothetical future world with mutual BMD deployments might therefore appeal to one analyst or nation, another could easily have a completely different view of the technical and strategic "facts."

Section 10

PRINCIPAL JUDGMENTS AND OBSERVATIONS

1. **The prospect that emerging "Star Wars" technologies, when further developed, will provide a perfect or near-perfect defense system, literally removing from the hands of the Soviet Union the ability to do socially mortal damage to the United States with nuclear weapons, is so remote that it should not serve as the basis of public expectation or national policy about ballistic missile defense (BMD).** This judgment appears to be the consensus among informed members of the defense technical community.

Technical prognosis for such a perfect or near-perfect defense is extremely pessimistic because of the concentration and fragility of society; because all concepts identified as candidates for a future defense of population are known to be susceptible to countermeasures that would permit the Soviet Union to retain a degree of penetration with their future missile arsenal despite costly attempts to improve the U.S. defense; because the Soviet Union would almost certainly make such a determined effort to avoid being disarmed by a U.S. defense; and because missile defense does not address other methods for delivering nuclear weapons to the United States.

Mutual assured destruction (MAD), if this term is applied to a state of technological existence rather than to a chosen national policy, is likely to persist for the foreseeable future.

2. **The wisdom of deploying less-than-perfect ballistic missile defenses remains controversial.** Less-than-perfect defenses would still allow the Soviet Union to destroy U.S. society in a massive attack but might call into question the effectiveness of smaller, specialized nuclear strikes.

Certain theories about nuclear war maintain that such defenses could lessen the chances of nuclear war and enhance U.S. security by protecting U.S. retaliatory forces; by interdicting "limited" nuclear strikes; by further confusing Soviet predictions of the outcome of a strike; by driving Soviet missile deployments in directions favored by the United States; by lessening the consequences of nuclear attack; and/or by fulfilling still other strategic goals.

Critics dispute the validity of some of these goals; dispute that technology can fulfill the truly useful goals; and/or argue that the many harmful side effects of introducing BMD to the strategic equation and altering the Anti-Ballistic Missile (ABM) Treaty regime are not worth satisfying these goals.

To address the wisdom of less-than-perfect defense, the public and policymakers would need a precise statement of the strategic goal of the deployment, an assessment of whether technology could satisfy that goal, and an analysis balancing fulfillment of the goal against the side effects and uncertainties of introducing a new ingredient into the strategic nuclear arena.

3. **The strategic goal of President Reagan's Strategic Defense Initiative calling for emphasized BMD research—perfect, near-perfect, or less-than-perfect defense against ballistic missiles—remains unclear.** No explicit technical standards or criteria are therefore available against which to measure the technological prospects and progress of this initiative.

4. **In all cases, directed-energy weapons and other devices with the specifications needed for boost-phase intercept of ICBMs have not yet been built in the laboratory, much less in a form suitable for incorporation in a complete defense system.** These devices include chemical lasers, excimer and free electron lasers, x-ray lasers, particle beams, lightweight high-velocity kinetic energy weapons, and microwave generators, together with tracking, aiming, and pointing mechanisms, power sources, and other essential accompaniments.

It is unknown whether or when devices with the required specifications can be built.

5. **Moreover, making the technological devices perform to the needed specifications in a controlled situation is not the crux of the technical challenge facing designers of an effective ballistic missile defense. A distinct challenge is to fashion from these devices a reliable defensive architecture, taking into account vulnerability**

of the defense components, susceptibility to future Soviet countermeasures, and cost relative to those countermeasures.

New intercept mechanisms—directed energy weapons and the like—therefore do not by themselves necessarily herald dramatically new BMD capabilities.

6. **It is clear that potent directed-energy weapons will be developed for other military purposes, even if such weapons are never incorporated into effective BMDs.** Such weapons might have a role in nuclear offense as well as defense, in anti-satellite (ASAT) attack, in anti-aircraft attack, and in other applications of concern to nuclear policy and arms control. Defense and arms control policy will thus need to face the advent of these new weapons, irrespective of their BMD dimension.

7. **For modest defensive goals requiring less-than-perfect performance, traditional reentry phase defenses and/or more advanced mid-course defenses might suffice.** Such defenses present less technical risk than systems that incorporate a boost-phase layer, and they could probably be deployed more quickly.

New ideas for improving such "old" BMD concepts have emerged in the atmosphere of technical optimism enjoyed by the boost-phase concepts.

8. **Deployment of missile defenses based on new technologies is forbidden by the Anti-Ballistic Missile (ABM) Treaty reached at SALT I.** The Treaty permits only restricted deployment of traditional BMDs using fixed, ground-based radars and interceptor missiles. Research into new technologies, and in selected cases development and testing of defense systems based on these technologies, are allowed within the Treaty.

9. **There is a close connection, not explored in detail in this Background Paper, between advanced BMD concepts and future anti-satellite (ASAT) systems.** This connection springs from four observations: 1) ASAT attack on space-based weapons and sensors is probably the most attractive countermeasure to boost-phase BMD; 2) directed-energy weapons are more likely to succeed in the easier mission of ASAT than in the more difficult mission of boost-phase BMD; 3) to a degree dependent on technical details, early stages of development of boost phase BMDs might be conducted in the guise of ASAT development, stimulating anxieties about the health of the ABM Treaty regime; 4) to a degree dependent on technical details, concluding a treaty with the Soviet Union limiting ASAT development would impede BMD research at an earlier stage than would occur under the terms of the ABM Treaty alone.

APPENDIX A: THE CONCLUSION OF PRESIDENT REAGAN'S MARCH 23, 1983, SPEECH ON DEFENSE SPENDING AND DEFENSIVE TECHNOLOGY

Weekly Compilation of

Presidential Documents

Monday, March 28, 1983
Volume 19—Number 12
Pages 423–466

Now, thus far tonight I've shared with you my thoughts on the problems of national security we must face together. My predecessors in the Oval Office have appeared before you on other occasions to describe the threat posed by Soviet power and have proposed steps to address that threat. But since the advent of nuclear weapons, those steps have been increasingly directed toward deterrence of aggression through the promise of retaliation.

This approach to stability through offensive threat has worked. We and our allies have succeeded in preventing nuclear war for more than three decades. In recent months, however, my advisers, including in particular the Joint Chiefs of Staff, have underscored the necessity to break out of a future that relies solely on offensive retaliation for our security.

Over the course of these discussions, I've become more and more deeply convinced that the human spirit must be capable of rising above dealing with other nations and human beings by threatening their existence. Feeling this way, I believe we must thoroughly examine every opportunity for reducing tensions and for introducing greater stability into the strategic calculus on both sides.

One of the most important contributions we can make is, of course, to lower the level of all arms, and particularly nuclear arms. We're engaged right now in several negotiations with the Soviet Union to bring about a mutual reduction of weapons. I will report to you a week from tomorrow my thoughts on that score. But let me just say, I'm totally committed to this course.

If the Soviet Union will join with us in our effort to achieve major arms reduction, we will have succeeded in stabilizing the nuclear balance. Nevertheless, it will still be necessary to rely on the specter of retaliation, on mutual threat. And that's a sad commentary on the human condition. Wouldn't it be better to save lives than to avenge them? Are we not capable of demonstrating our peaceful intentions by applying all our abilities and our ingenuity to achieving a truly lasting stability? I think we are. Indeed, we must.

After careful consultation with my advisers, including the Joint Chiefs of Staff, I believe there is a way. Let me share with you a vision of the future which offers hope. It is that we embark on a program to counter the awesome Soviet missile threat with measures that are defensive. Let us turn to the very strengths in technology that spawned our great industrial base and that have given us the quality of life we enjoy today.

What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack, that we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies?

I know this is a formidable, technical task, one that may not be accomplished before the end of this century. Yet, current technology has attained a level of sophistication where it's reasonable for us to begin this effort. It will take years, probably decades of effort on many fronts. There will be failures and setbacks, just as there will be successes and breakthroughs. And as we proceed, we must remain constant in preserving the nuclear deterrent and maintaining a solid capability for flexible response. But isn't it worth every investment necessary to free the world from the threat of nuclear war? We know it is.

In the meantime, we will continue to pursue real reductions in nuclear arms, negotiating from a position of strength that can be ensured only by modernizing our strategic forces. At the same time, we must take steps to reduce the risk of a conventional military conflict escalating to nuclear war by improving our non-nuclear capabilities.

America does possess—now—the technologies to attain very significant improvements in the effectiveness of our conventional, non-nuclear forces. Proceeding boldly with these new technologies, we can significantly reduce any incentive that the Soviet Union may have to threaten attack against the United States or its allies.

As we pursue our goal of defensive technologies, we recognize that our allies rely upon our strategic offensive power to deter attacks against them. Their vital interests and ours are inextricably linked. Their safety and ours are one. And no change in technology can or will alter that reality. We must and shall continue to honor our commitments.

I clearly recognize that defensive systems have limitations and raise certain problems and ambiguities. If paired with offensive systems, they can be viewed as fostering an aggressive policy, and no one wants that. But with these considerations firmly in mind, I call upon the scientific community in our country, those who gave us nuclear weapons, to turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impotent and obsolete.

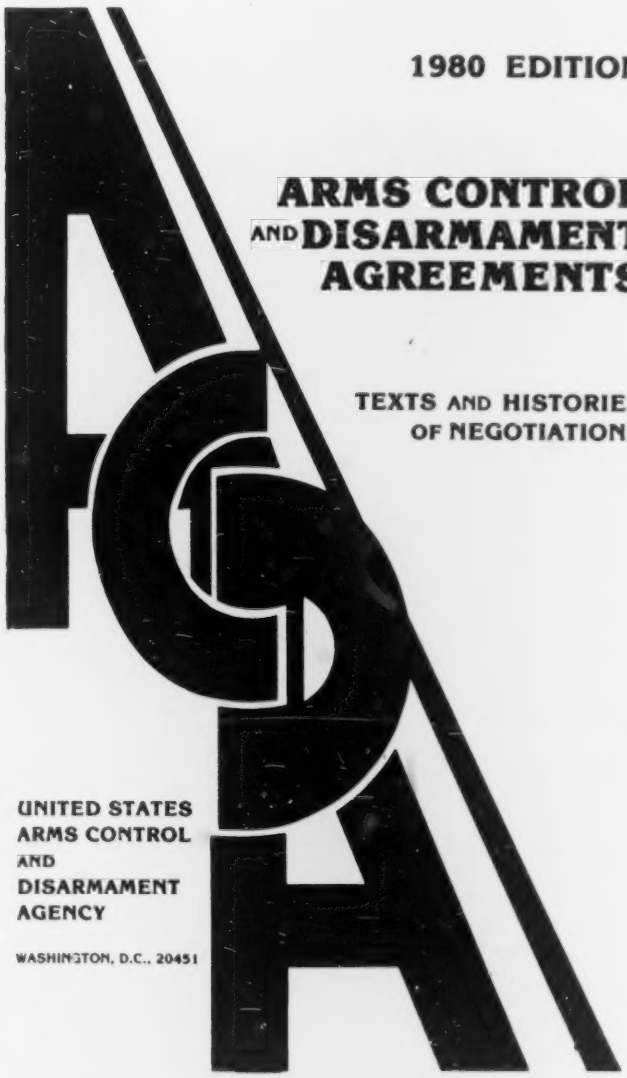
Tonight, consistent with our obligations of the ABM treaty and recognizing the need for closer consultation with our allies, I'm taking an important first step. I am directing a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles. This could pave the way for arms control measures to eliminate the weapons themselves. We seek neither military superiority nor political advantage. Our only purpose—one all people share—is to search for ways to reduce the danger of nuclear war.

My fellow Americans, tonight we're launching an effort which holds the promise of changing the course of human history. There will be risks, and results take time. But I believe we can do it. As we cross this threshold, I ask for your prayers and your support.

Thank you, good night, and God bless you.

Note: The President spoke at 8:02 p.m. from the Oval Office at the White House. The address was broadcast live on nationwide radio and television.

Following his remarks, the President met in the White House with a number of administration officials, including members of the Cabinet, the White House staff, and the Joint Chiefs of Staff, and former officials of past administrations to discuss the address.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WASHINGTON, D.C., 20451

Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems

Signed at Moscow May 26, 1972
Ratification advised by U.S. Senate August 3, 1972
Ratified by U.S. President September 30, 1972
Proclaimed by U.S. President October 3, 1972
Instruments of ratification exchanged October 3, 1972
Entered into force October 3, 1972

The United States of America and the Union of Soviet Socialist Republics, hereinafter referred to as the Parties,

Proceeding from the premise that nuclear war would have devastating consequences for all mankind,

Considering that effective measures to limit anti-ballistic missile systems would be a substantial factor in curbing the race in strategic offensive arms and would lead to a decrease in the risk of outbreak of war involving nuclear weapons,

Proceeding from the premise that the limitation of anti-ballistic missile systems, as well as certain agreed measures with respect to the limitation of strategic offensive arms, would contribute to the creation of more favorable conditions for further negotiations on limiting strategic arms,

Mindful of their obligations under Article VI of the Treaty on the Non-Proliferation of Nuclear Weapons,

Declaring their intention to achieve at the earliest possible date the cessation of the nuclear arms race and to take effective measures toward reductions in strategic arms, nuclear disarmament, and general and complete disarmament,

Desiring to contribute to the relaxation of international tension and the strengthening of trust between States,

Have agreed as follows:

Article I

1. Each party undertakes to limit anti-ballistic missile (ABM) systems and to adopt other measures in accordance with the provisions of this Treaty.

2. Each Party undertakes not to deploy ABM systems for a defense of the territory of its country and not to provide a base for such a defense, and not to deploy ABM systems for defense of an individual region except as provided for in Article III of this Treaty.

Article II

1. For the purpose of this Treaty an ABM system is a system to counter strategic ballistic missiles or their elements in flight trajectory, currently consisting of:

(a) ABM interceptor missiles, which are interceptor missiles constructed and deployed for an ABM role, or of a type tested in an ABM mode;

(b) ABM launchers, which are launchers constructed and deployed for launching ABM interceptor missiles; and

(c) ABM radars, which are radars constructed and deployed for an ABM role, or of a type tested in an ABM mode.

2. The ABM system components listed in paragraph 1 of this Article include those which are:

(a) operational;
(b) under construction;
(c) undergoing testing;
(d) undergoing overhaul, repair or conversion; or
(e) mothballed.

Article III

Each Party undertakes not to deploy ABM systems or their components except that:

(a) within one ABM system deployment area having a radius of one hundred and fifty kilometers and centered on the Party's national capital, a Party may deploy: (1) no more than one hundred ABM launchers and no more than one hundred ABM interceptor missiles at launch sites, and (2) ABM radars within no more than six ABM radar complexes, the area of each complex being circular and having a diameter of no more than three kilometers; and

(b) within one ABM system deployment area having a radius of one hundred and fifty kilometers and containing ICBM silo launchers, a Party may deploy: (1) no more than one hundred ABM launchers and no more than one hundred ABM interceptor missiles at launch sites, (2) two large phased-array ABM radars comparable in potential to corresponding ABM radars operational or under construction on the date of signature of the Treaty in an ABM system deployment area containing ICBM silo launchers, and (3) no more than eighteen ABM radars each having a potential less than the potential of the smaller of the above-mentioned two large phased-array ABM radars.

Article IV

The limitations provided for in Article III shall not apply to ABM systems or their components used for development or testing, and located within current or additionally agreed test ranges. Each Party may have no more than a total of fifteen ABM launchers at test ranges.

Article V

1. Each Party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based.

2. Each Party undertakes not to develop, test, or deploy ABM launchers for launching more than one ABM interceptor missile at a time from each launcher, not to modify deployed launchers to provide them with such a capability, not to develop, test, or deploy automatic or semi-automatic or other similar systems for rapid reload of ABM launchers.

Article VI

To enhance assurance of the effectiveness of the limitations on ABM systems and their components provided by the Treaty, each Party undertakes:

(a) not to give missiles, launchers, or radars, other than ABM interceptor missiles, ABM launchers, or ABM radars, capabilities to counter strategic ballistic missiles or their elements in flight trajectory, and not to test them in an ABM mode; and

(b) not to deploy in the future radars for early warning of strategic ballistic missile attack except at locations along the periphery of its national territory and oriented outward.

Article VII

Subject to the provisions of this Treaty, modernization and replacement of ABM systems or their components may be carried out.

Article VIII

ABM systems or their components in excess of the numbers or outside the areas specified in this Treaty, as well as ABM systems or their components prohibited by this Treaty, shall be destroyed or dismantled under agreed procedures within the shortest possible agreed period of time.

Article IX

To assure the viability and effectiveness of this Treaty, each Party undertakes not to transfer to other States, and not to deploy outside its national territory, ABM systems or their components limited by this Treaty.

Article X

Each Party undertakes not to assume any international obligations which would conflict with this Treaty.

Article XI

The Parties undertake to continue active negotiations for limitations on strategic offensive arms.

Article XII

1. For the purpose of providing assurance of compliance with the provisions of this Treaty, each Party shall use national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.

2. Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this Article.

3. Each Party undertakes not to use deliberate concealment measures which impede verification by national technical means of compliance with the provisions of this Treaty. This obligation shall not require changes in current construction, assembly, conversion, or overhaul practices.

Article XIII

1. To promote the objectives and implementation of the provisions of this Treaty, the Parties shall establish promptly a Standing Consultative Commission, within the framework of which they will:

(a) consider questions concerning compliance with the obligations assumed and related situations which may be considered ambiguous;

(b) provide on a voluntary basis such information as either Party considers necessary to assure confidence in compliance with the obligations assumed;

(c) consider questions involving unintended interference with national technical means of verification;

(d) consider possible changes in the strategic situation which have a bearing on the provisions of this Treaty;

(e) agree upon procedures and dates for destruction or dismantling of ABM systems or their components in cases provided for by the provisions of this Treaty;

(f) consider, as appropriate, possible proposals for further increasing the viability of this Treaty, including proposals for amendments in accordance with the provisions of this Treaty;

(g) consider, as appropriate, proposals for further measures aimed at limiting strategic arms.

2. The Parties through consultation shall establish, and may amend as appropriate, Regulations for the Standing Consultative Commission governing procedures, composition and other relevant matters.

Article XIV

1. Each Party may propose amendments to this Treaty. Agreed amendments shall enter into force in accordance with the procedures governing the entry into force of this Treaty.

2. Five years after entry into force of this Treaty, and at five-year intervals thereafter, the Parties shall together conduct a review of this Treaty.

Article XV

1. This Treaty shall be of unlimited duration.

2. Each Party shall, in exercising its national sovereignty, have the right to withdraw from this Treaty if it decides that extraordinary events related to the subject matter of this Treaty have jeopardized its supreme interests. It shall give notice of its decision to the other Party six months prior to withdrawal from the Treaty. Such notice shall include a statement of the extraordinary events the notifying Party regards as having jeopardized its supreme interests.

Article XVI

1. This Treaty shall be subject to ratification in accordance with the constitutional procedures of each Party. The Treaty shall enter into force on the day of the exchange of instruments of ratification.

2. This Treaty shall be registered pursuant to Article 102 of the Charter of the United Nations.

DONE at Moscow on May 26, 1972, in two copies, each in the English and Russian languages, both texts being equally authentic.

FOR THE UNITED STATES OF AMERICA

President of the United States of America

FOR THE UNION OF SOVIET SOCIALIST REPUBLICS

General Secretary of the Central Committee of the CPSU

Agreed Statements, Common Understandings, and Unilateral Statements Regarding the Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missiles

1. Agreed Statements

The document set forth below was agreed upon and initialed by the Heads of the Delegations on May 26, 1972 (letter designations added):

AGREED STATEMENTS REGARDING THE TREATY BETWEEN THE UNITED STATES OF AMERICA AND THE UNION OF SOVIET SOCIALIST REPUBLICS ON THE LIMITATION OF ANTI-BALLISTIC MISSILE SYTEMS

[A]

The Parties understand that, in addition to the ABM radars which may be deployed in accordance with subparagraph (a) of Article III of the Treaty, those non-phased-array ABM radars operational on the date of signature of the Treaty within the ABM system deployment area for defense of the national capital may be retained.

[B]

The Parties understand that the potential (the product of mean emitted power in watts and antenna area in square meters) of the smaller of the two large phased-array ABM radars referred to in subparagraph (b) of Article III of the Treaty is considered for purposes of the Treaty to be three million.

[C]

The Parties understand that the center of the ABM system deployment area centered on the national capital and the center of the ABM system deployment area containing ICBM silo launchers for each Party shall be separated by no less than thirteen hundred kilometers.

[D]

In order to insure fulfillment of the obligation not to deploy ABM systems and their components except as provided in Article III of the Treaty, the Parties agree that in the event ABM systems based on other physical principles and including components capable of substituting for ABM interceptor missiles, ABM launchers, or ABM radars are created in the future, specific limitations on such systems and their components would be subject to discussion in accordance with Article XIII and agreement in accordance with Article XIV of the Treaty.

[E]

The Parties understand that Article V of the Treaty includes obligations not to develop, test or deploy ABM interceptor missiles for the delivery by each ABM interceptor missile of more than one independently guided warhead.

[F]

The Parties agree not to deploy phased-array radars having a potential (the product of mean emitted power in watts and antenna area in square meters) exceeding three million, except as provided for in Articles III, IV and VI of the Treaty, or except for the purposes of tracking objects in outer space or for use as national technical means of verification.

[G]

The Parties understand that Article IX of the Treaty includes the obligation of the US and the USSR not to provide to other States technical descriptions or blue prints specially worked out for the construction of ABM systems and their components limited by the Treaty.

2. Common Understandings

Common understanding of the Parties on the following matters was reached during the negotiations:

A. Location of ICBM Defenses

The U.S. Delegation made the following statement on May 26, 1972:

Article III of the ABM Treaty provides for each side one ABM system deployment area centered on its national capital and one ABM system deployment area containing ICBM silo launchers. The two sides have registered agreement on the following statement: "The Parties understand that the center of the ABM system deployment area centered on the national capital and the center of the ABM system deployment area containing ICBM silo launchers for each Party shall be separated by no less than thirteen hundred kilometers." In this connection, the U.S. side notes that its ABM system deployment area for defense of ICBM silo launchers, located west of the Mississippi River, will be centered in the Grand Forks ICBM silo launcher deployment area. (See Agreed Statement [C].)

B. ABM Test Ranges

The U.S. Delegation made the following statement on April 26, 1972:

Article IV of the ABM Treaty provides that "the limitations provided for in Article III shall not apply to ABM systems or their components used for development or testing, and located within current or additionally agreed test ranges." We believe it would be useful to assure that there is no misunderstanding as to current ABM test ranges. It is our understanding that ABM test ranges encompass the area within which ABM components are located for test purposes. The current U.S. ABM test ranges are at White Sands, New Mexico, and at Kwajalein Atoll, and the current Soviet ABM test range is near Sary Shagan in Kazakhstan. We consider that non-phased array radars of types used for range safety or instrumentation purposes may be located outside of ABM test ranges. We interpret the reference in Article IV to "additionally agreed test

ranges" to mean that ABM components will not be located at any other test ranges without prior agreement between our Governments that there will be such additional ABM test ranges.

On May 5, 1972, the Soviet Delegation stated that there was a common understanding on what ABM test ranges were, that the use of the types of non-ABM radars for range safety or instrumentation was not limited under the Treaty, that the reference in Article IV to "additionally agreed" test ranges was sufficiently clear, and that national means permitted identifying current test ranges.

C. Mobile ABM Systems

On January 29, 1972, the U.S. Delegation made the following statement:

Article V(1) of the Joint Draft Text of the ABM Treaty includes an undertaking not to develop, test, or deploy mobile land-based ABM systems and their components. On May 5, 1971, the U.S. side indicated that, in its view, a prohibition on deployment of mobile ABM systems and components would rule out the deployment of ABM launchers and radars which were not permanent fixed types. At that time, we asked for the Soviet view of this interpretation. Does the Soviet side agree with the U.S. side's interpretation put forward on May 5, 1971?

On April 13, 1972, the Soviet Delegation said there is a general common understanding on this matter.

D. Standing Consultative Commission

Ambassador Smith made the following statement on May 22, 1972:

The United States proposes that the sides agree that, with regard to initial implementation of the ABM Treaty's Article XIII on the Standing Consultative Commission (SCC) and of the consultation Articles to the Interim Agreement on offensive arms and the Accidents Agreement,[1] agreement establishing the SCC will be worked out early in the follow-on SALT negotiations; until that is completed, the following arrangements will prevail: when SALT is in session, any consultation desired by either side under these Articles can be carried out by the two SALT Delegations; when SALT is not in session, *ad hoc* arrangements for any desired consultations under these Articles may be made through diplomatic channels.

Minister Semenov replied that, on an *ad referendum* basis, he could agree that the U.S. statement corresponded to the Soviet understanding.

E. Standstill

On May 6, 1972, Minister Semenov made the following statement:

In an effort to accommodate the wishes of the U.S. side, the Soviet Delegation is prepared to proceed on the basis that the two sides will in fact observe the obligations of both the Interim Agreement and the ABM Treaty beginning from the date of signature of these two documents.

In reply, the U.S. Delegation made the following statement on May 20, 1972:

---

[1]See Article 7 of Agreement to Reduce the Risk of Outbreak of Nuclear War Between the United States of America and the Union of Soviet Socialist Republics, signed Sept. 30, 1971.

The U.S. agrees in principle with the Soviet statement made on May 6 concerning observance of obligations beginning from date of signature but we would like to make clear our understanding that this means that, pending ratification and acceptance, neither side would take any action prohibited by the agreements after they had entered into force. This understanding would continue to apply in the absence of notification by either signatory of its intention not to proceed with ratification or approval.

The Soviet Delegation indicated agreement with the U.S. statement.

3. Unilateral Statements

The following noteworthy unilateral statements were made during the negotiations by the United States Delegation:

A. Withdrawal from the ABM Treaty

On May 9, 1972, Ambassador Smith made the following statement:

The U.S. Delegation has stressed the importance the U.S. Government attaches to achieving agreement on more complete limitations on strategic offensive arms, following agreement on an ABM Treaty and on an Interim Agreement on certain measures with respect to the limitation of strategic offensive arms. The U.S. Delegation believes that an objective of the follow-on negotiations should be to constrain and reduce on a long-term basis threats to the survivability of our respective strategic retaliatory forces. The USSR Delegation has also indicated that the objectives of SALT would remain unfulfilled without the achievement of an agreement providing for more complete limitations on strategic offensive arms. Both sides recognize that the initial agreements would be steps toward the achievement of more complete limitations on strategic arms. If an agreement providing for more complete strategic offensive arms limitations were not achieved within five years, U.S. supreme interests could be jeopardized. Should that occur, it would constitute a basis for withdrawal from the ABM Treaty. The U.S. does not wish to see such a situation occur, nor do we believe that the USSR does. It is because we wish to prevent such a situation that we emphasize the importance the U.S. Government attaches to achievement of more complete limitations on strategic offensive arms. The U.S. Executive will inform the Congress, in connection with Congressional consideration of the ABM Treaty and the Interim Agreement, of this statement of the U.S. position.

B. Tested in ABM Mode

On April 7, 1972, the U.S. Delegation made the following statement:

Article II of the Joint Text Draft uses the term "tested in an ABM mode," in defining ABM components, and Article VI includes certain obligations concerning such testing. We believe that the sides should have a common understanding of this phrase. First, we would note that the testing provisions of the ABM Treaty are intended to apply to testing which occurs after the date of signature of the Treaty, and not to any testing which may have occurred in the past. Next, we would amplify the remarks we have made on this subject during the previous Helsinki phase by setting forth the objectives which govern the U.S. view on the subject, namely, while prohibiting testing of non-ABM components for ABM purposes: not to prevent testing of ABM components, and not to prevent testing of non-ABM components for

non-ABM purposes. To clarify our interpretation of "tested in an ABM mode," we note that we would consider a launcher, missile or radar to be "tested in an ABM mode" if, for example, any of the following events occur: (1) a launcher is used to launch an ABM interceptor missile, (2) an interceptor missile is flight tested against a target vehicle which has a flight trajectory with characteristics of a strategic ballistic missile flight trajectory, or is flight tested in conjunction with the test of an ABM interceptor missile or an ABM radar at the same test range, or is flight tested to an altitude inconsistent with interception of targets against which air defenses are deployed, (3) a radar makes measurements on a cooperative target vehicle of the kind referred to in item (2) above during the reentry portion of its trajectory or makes measurements in conjunction with the test of an ABM interceptor missile or an ABM radar at the same test range. Radars used for purposes such as range safety or instrumentation would be exempt from application of these criteria.

C. No-Transfer Article of ABM Treaty

On April 18, 1972, the U.S. Delegation made the following statement:

In regard to this Article [IX], I have a brief and I believe self-explanatory statement to make. The U.S. side wishes to make clear that the provisions of this Article do not set a precedent for whatever provision may be considered for a Treaty on Limiting Strategic Offensive Arms. The question of transfer of strategic offensive arms is a far more complex issue, which may require a different solution.

D. No Increase in Defense of Early Warning Radars

On July 28, 1970, the U.S. Delegation made the following statement:

Since Hen House radars [Soviet ballistic missile early warning radars] can detect and track ballistic missile warheads at great distances, they have a significant ABM potential. Accordingly, the U.S. would regard any increase in the defenses of such radars by surface-to-air missiles as inconsistent with an agreement.

APPENDIX C: OTHER APPLICATIONS OF DIRECTED ENERGY WEAPONS

This Background Paper treats only one—and probably one of the most difficult—military application of directed energy. Many other applications of widely varying plausibility vie for funding and attention. An assessment of all these schemes is well beyond the scope of this Paper, but the list below is provided for reference. Mention of a scheme does not imply that it has any technical or military promise; this question would have to be properly studied.

Anti-satellite (ASAT). Directed energy attack on satellites from space-, air-, or ground-based weapons is substantially easier than boost phase BMD. A satellite's orbit is completely predictable, making it in effect a fixed target. Long dwell times and low fluences suffice for ASAT attack on unshielded satellites. For instance, long illumination at just a few watts/cm² (several times the sun's normal irradiance in space) could upset the thermal control systems that allow spacecraft to endure the extremes of heat and cold in outer space. Substantial hardening of large and complex satellites (including sensors) to directed energy weapons from all directions at all times is impractical. Unlike BMD, which must handle thousands of boosters in a few minutes, ASATs would have fewer targets and longer attack times. Last, BMDs must operate under the most hostile circumstances imaginable, whereas the superpowers might use ASATs in scenarios short of nuclear war.

This Background Paper has stressed (see Section 5.1) that maturation of the same technologies involved in boost phase BMD virtually assures potent ASATs. The so-called "Star Wars" systems could well be their own worst threats. Besides the intrinsic ease of ASAT over BMD, a Soviet defense suppression ASAT attack on U.S. defensive battle stations would have three key factors working in its favor: 1) The Soviets would pick the time and sequence of attack on the U.S. BMD system and launch of their ICBMs; 2) The Soviets need not destroy the entire defensive constellation, but only "punch a hole" for their ICBMs to pass through; 3) The attack would take place over Soviet territory.

Ground-based laser ASATs, presumably using excimer or free-electron lasers for best atmospheric propagation, would have the advantages of large size and power supplies. Airborne lasers could avoid some of the propagation disturbances introduced by denser air at low altitudes, but turbulence around the airplane skin could require adaptive beam compensation.

Space-based directed energy ASATs are the most interesting category of all, since they would be, in effect, long-range space mines. Rather than positioning itself next to its quarry like an ordinary space mine, a laser could be thousands of kilometers away and still be able to strike within milliseconds upon receipt of a radio signal from the gound.

Strategic offense. If they mature, the directed energy devices discussed for BMD might turn out to have been better termed "offensive breakthroughs" than "defensive breakthroughs." Consider, for example, a fleet of Soviet x-ray lasers launched simultaneously with (or minutes before) a Soviet first-stike ICBM attack. The pop-up x-ray lasers' job would be to intercept any U.S. ICBMs launched before arrival of Soviet silo-killing RVs. The Soviet x-ray lasers would therefore deprive the U.S. of its option for launch under attack. Microwave generators might be used for EMP-like attack on the U.S. command and control system. Another example of offensive use of beam weapons would be Soviet ASAT attack on U.S. warning, communications, nuclear detonation detection, or navigation satellites important to the U.S. rataliatory capability. Yet another example would of course be suppression of any U.S. BMD that used space-based weapons or sensors.

Bus intercept. This Background Paper has focused on intercept of ICBMs before booster burnout. Intercept of the bus or post boost vehicle poses a rather different challenge. Post-boost phase for today's ICBMs is rather long (several minutes) but could be shortened drastically on future ICBMs. Bus tracking requires a different sensor than booster tracking, since the bus plume

is much less conspicuous, and the bus rocket motor may not operate continuously. The bus is a target of declining value as it dispenses its RVs. Interruption of bus operation would not prevent the bus and its contents from continuing their ballistic flight to the target country, though the aim might be very wide of the target. Operating above the atmosphere, the bus can deploy lightweight shields, decoys, and sensor countermeasures (e.g., corner reflectors). On the other hand, x-ray lasers and neutral particle beams that cannot penetrate the atmosphere can attack the bus in space.

Anti-SLBM. A number of schemes have been suggested for using directed energy weapons against SLBMs, besides the obvious extensions of ICBM defense. Thus pop-up x-ray lasers could be positioned on U.S. coasts or ships at sea to intercept SLBMs launched from nearby Soviet submarines. Aircraft patrolling coastal waters and carrying lasers could attack ascending SLBMs in their area.

Anti-IRBM. Intermediate range ballistic missiles (IRBMs) have short boost phases and potentially low trajectories, making anti-IRBM defense rather different from anti-ICBM defense and perhaps better accomplished with ground-based terminal BMD systems deployed in the theater.

Defense of satellites (DSAT). Low-power wide-divergence (small optics) laser satellites (perhaps HF for high specific energy) could serve as "escorts" for other satellites, defending the other satellites from hostile objects—mines, ASAT missiles —approaching within a given range.

Anti-aircraft. At least four schemes have been broached for using directed energy weapons against aircraft or cruise missiles. The most ambitious would involve a worldwide constellation of trackers (possibly LWIR) and beam weapons (possibly DF or short wavelength lasers) to attack Soviet Blackjack strategic bombers, Backfire bombers attacking U.S. aircraft carriers, Soviet airborne command post "Doomsday planes," Soviet AWACS radar planes, and so on. In a second scheme, B-1 or B-52 bombers would be outfitted with lasers (possibly DF) to protect them from Soviet fighters, surface-to-air missiles (SAMs), and air-to-air missiles. A third scheme equips carrier battle groups with lasers or particle beams to defend themselves against cruise missile attack. Fourth and last, ground-based beam weapons might replace surface-to-air missiles for local air defense.

Midcourse and terminal BMD. Intense electron beams have long been studied as replacements for interceptors in reentry BMD. In midcourse BMD, beam weapons might not only destroy RVs, but aid discrimination of RVs from lightweight decoys: lasers, particle beams, or x-ray lasers would illuminate approaching objects, and sensors would use the response of each object as an extra piece of data to judge whether it was a true RV (see Section 6).

Submarine communications. This scheme would use a blue-green laser to communicate with submerged submarines. Seawater is opaque to all but VLF and ELF radio frequencies, used for submarine communications today, and to the blue-green portion of the visible light spectrum. A blue-green laser beam originating on a satellite, reflected from a space-based mirror, or carried by an airplane would be modulated in accordance with the message to be transmitted and directed at a given spot on the ocean. After transmission of the full message, the beam would dwell on a neighboring spot and transmit again, and so on, eventually covering all submarine patrol areas. Optical sensors on the submarine hull would detect the message.

Blinding sensors and seekers. Analysts have studied a wide range of tactical applications for lasers, involving blinding of battlefield sensors, missile seekers, and even human beings.

Office of Technology Assessment

The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts that can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

Requests for studies are made by chairmen of standing committees of the House of Representatives or Senate; by the Technology Assessment Board, the governing body of OTA; or by the Director of OTA in consultation with the Board.

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OTA has studies under way in nine program areas: energy and materials; industry, technology, and employment; international security and commerce; biological applications; food and renewable resources; health; communication and information technologies; oceans and environment; and science, transportation, and innovation.

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Arms Control in Space

Workshop Proceedings

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

Office of Technology Assessment

Congressional Board of the 98th Congress

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University of Arizona

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Director

JOHN H. GIBBONS

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Arms Control in Space

Workshop Proceedings

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

Workshop on Arms Control in Space
January 30-31, 1984

Prof. McGeorge Bundy, *Chair*
New York University, New York, N.Y.

Mr. David S. Brandwein
System Planning Corp.
Arlington, Va.

The Hon. George E. Brown, Jr.
Member of Congress
U.S. House of Representatives
Washington, D.C.

Dr. Paul Brown
Lawrence Livermore National Laboratory
Livermore, Calif.

Dr. Robert W. Buchheim
Phoenix, Ariz.

Prof. Albert Carnesale
JFK School of Government
Harvard University
Cambridge, Mass.

Dr. Ashton B. Carter
Center for International Studies
Massachusetts Institute of Technology
Cambridge, Mass.

The Hon. Cooper Evans
Member of Congress
U.S. House of Representatives
Washington, D.C.

Dr. Richard L. Garwin
IBM Thomas J. Watson Research Center
Yorktown Heights, N.Y.

Dr. John H. Gibbons
Director
Office of Technology Assessment
U.S. Congress
Washington, D.C.

Mr. Alex Gliksman
Senate Committee on Foreign Relations
Washington, D.C.

Prof. Donald L. Hafner
Boston College
Chestnut Hill, Mass.

Mr. Lionel S. Johns
Assistant Director
Office of Technology Assessment
U.S. Congress
Washington, D.C.

Dr. Robert H. Kupperman
Center for Strategic and International Studies
Georgetown University
Washington, D.C.

Dr. Steven A. Maaranen
Los Alamos National Laboratory
Los Alamos, N.Mex.

Dr. Michael M. May
Lawrence Livermore National Laboratory
Livermore, Calif.

Dr. Keith B. Payne
National Institute for Public Policy
Fairfax, Va.

Mr. John E. Pike
Federation of American Scientists
Washington, D.C.

The Hon. Larry Pressler
Member of Congress
United States Senate
Washington, D.C.

Dr. Victor W. Reis
Science Applications, Inc.
McLean, Va.

Dr. Peter Sharfman
Program Manager
Office of Technology Assessment
U.S. Congress
Washington, D.C.

Walter Slocombe, Esq.
Caplin and Drysdale
Washington, D.C.

Dr. John D. Steinbruner
Director, Foreign Policy Studies
The Brookings Institution
Washington, D.C.

MGen. Henry B. Stelling, Jr., USAF (ret.)
Rockwell International
Anaheim, Calif.

Dr. Sayre Stevens
System Planning Corp.
Arlington, Va.

NOTE: Several participants were originally invited as alternates for others who could not attend the entire workshop.

OTA Arms Control in Space Workshop Staff

Lionel S. Johns, *Assistant Director, OTA*
Energy, Materials, and International Security Division

Peter Sharfman, *International Security and Commerce Program Manager*

Gerald Epstein, *Workshop Rapporteur*

Bruce Blair

Thomas H. Karas

Administrative Staff

Jannie Coles Dorothy Richroath Jackie Robinson

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Summary

In late 1982 and early 1983, the Subcommittee on Arms Control, Oceans, International Operations, and Environment of the Senate Committee on Foreign Relations held hearings on space weapons and arms control. To explore these issues further in a discussion format not easily achieved in hearings, Sen. Larry Pressler, Chairman of the Subcommittee, asked OTA to conduct a workshop focusing on anti-satellite (ASAT) weapons as one aspect of space arms control. The workshop, held in Washington, D.C., on January 30 and 31, 1984, provided an opportunity for technical, diplomatic, military, and policy-analysis experts to interact, think out loud, and build upon each other's ideas.

The workshop was organized into six sessions, although issues involving anti-satellite weapons and arms control are not easily compartmentalized into distinct subject areas. Each session was introduced by a 10- or 15-minute informal oral presentation which set the stage for further discussion. This workshop proceedings volume is organized along the same divisions as the sessions, with some rearrangement.

The first session, an overview, reviewed technical aspects of anti-satellite systems and presented a candidate set of topics for discussion in later sessions. The second session covered pros and cons of ASAT arms control. Soviet attitudes and efforts regarding ASATs were the focus of the third session; U.S. attitudes and developments in ASATs and ASAT arms control were reviewed in the fourth. The effect of ASATs on the continued viability of the 1972 Anti-Ballistic Missile (ABM) Treaty, and vice versa, were covered in the fifth session. The last session centered on verification issues.

At Senator Pressler's request, OTA is publishing the workshop proceedings. OTA's agreement with the panelists was that the workshop report would discuss the viewpoints, ideas, and findings arrived at during the conference, but that particular statements or opinions would not be attributed to specific individuals. Therefore, the transcript has been paraphrased and rearranged to form this report. The proceedings have been circulated among the panelists, who were given the opportunity to suggest corrections and clarifications. They have not been reviewed by the Technology Assessment Board.

The workshop panelists were asked to raise and clarify issues, not to resolve them. No attempt was made to reach conclusions or develop consenses during the workshop sessions. However, OTA has noted and listed below several points where the panelists appeared to be in general agreement. These points are followed by a brief discussion of some of the fundamental bases for disagreement among the panelists. Following that is a list of some issues, raised during the course of the workshop, which were felt to merit further research and analysis.

POINTS OF GENERAL AGREEMENT

No arms control agreement can eliminate all anti-satellite capability. However, panelists differed in interpreting the significance of this residual ASAT capability which would be infeasible or impractical to ban. Some systems not designed to be ASATs (ICBMs, manned spacecraft, etc.) nevertheless have some ASAT potential, making some de facto residual ASAT capability inevitable. ASAT arms control supporters stressed that it would be minor compared to the capability of extensive ASAT or "space mine" efforts which could be undertaken in the absence of an arms control agreement, while some of the ASAT arms con-

trol opponents believed that the residual capability might nevertheless pose a significant threat to U.S. satellites.

ASAT arms control cannot eliminate the need to protect or supplement vital satellites with a variety of survivability measures. However, it can serve to lessen the measures required to protect space systems. Under any arms control accord, programs to ensure survivability of critical satellites or programs which supplement or replace their function will remain vital. The temptation to assume that survivability measures could be relaxed following an agreement must be resisted. "We could be that stupid," said one panelist, "but we don't really have to be."

The "verifiability" of an ASAT accord can only be assessed for a specified set of restrictions and measures, and any discussion of the verifiability of a particular provision ought to include consideration of the significance of potential violations of that provision. The panelists did not evaluate in detail, partly because of security classification restrictions, the verifiability of compliance with the various kinds of arms control agreements that were discussed. It was clear that the standards of verification required for effective ASAT arms control are highly controversial. Panelists agreed, however, that bans on testing would require less extensive verification measures than bans on possession, and that compliance with some ASAT arms control provisions could be verified with high confidence.

Future U.S. and U.S.S.R. activities in space hold great potential for generating uncertainty and misunderstanding regarding the countries' respective intentions. Workshop participants agreed that the Soviet Union will continue its vigorous exploitation of space, and that some Soviet activities will be perceived in the United States as provocative. Similarly, some American actions will appear provocative to the Soviets. Both countries will observe activities which they will not completely understand and which will cause considerable concern. Misunderstandings concerning the intent of various space actions could be particularly dangerous during crises or low-level conflicts.

Ambiguities might be lessened or resolved with some type of "rules of the road" or "behavior in space" agreement. Some panelists thought that an agreement concerning behavior in space, or towards space objects, might serve to reduce tensions and uncertainties. Such an agreement need not be associated with other measures limiting anti-satellite weapons systems; indeed, there might be value even if (thought some panelists) or especially if (thought others) there were no accompanying ASAT restrictions. Such an agreement might be modeled after the "rules of the road" on the high seas, which are embodied in several international agreements that recognize freedom to operate, lessen the risk of accidental collision, and minimize unnecessary provocation at sea. Possibly the most valuable feature of a "rules of the road in space" agreement would be the establishment of a forum like the U.S.-U.S.S.R. Standing Consultative Commission, which would help maintain an ongoing dialog between the United States and the Soviet Union and would permit discussion of activities whose significance was not clear. A "rules of the road" agreement should not be allowed to impede more serious provisions concerning space weapons if such provisions are found to be desirable. The precise form of a "space behavior" agreement was not explored in depth at the workshop, and the political and diplomatic procedures and tradeoffs required to negotiate and implement such an agreement were not addressed.

If ASAT threats are reduced by an agreement, there may be fewer reservations about placing important systems in space, creating in turn greater incentive for developing ASAT weapons. If an accord has the effect of relaxing survivability measures at the same time that reliance on space systems is increasing, then the growth of targets both valuable and vulnerable might provide strong motivation to attempt covert ASAT development. This possible paradox reinforced panelists' observations that an ASAT accord is no substitute for effective measures to reduce space system vulnerability.

Preservation of the functions now performed in space does not require the survival of all space

assets. Military support activities carried out in space are very important, but they can be duplicated or distributed among many space systems. Furthermore, many alternatives to space-based systems exist or can be developed.

The idea that the United States needs an ASAT weapon in order to deter enemy ASAT attack was not strongly supported. Many participants felt that the ability to retaliate against terrestrial assets served to deter ASAT attack at least as well as the ability to respond in kind against enemy satellites. Furthermore, one of the rationales other than deterrence which has been given for the U.S. ASAT program—to carry out attacks on particularly hostile Soviet satellites—conflicts with the ASAT's deterrent role. Nobody at the workshop felt that ASAT attack scenarios were well enough understood to predict the outcome of "tit-for-tat" ASAT retaliatory attacks in general. The likelihood and nature of subsequent escalation would be highly dependent on which satellites were attacked and under what circumstances.

The U.S. air-launched ASAT weapon now undergoing testing is clearly technically superior to the present generation of Soviet ground-launched ASATs. The ability to home in from a wide range of directions, and the flexibility of being launched from highly mobile aircraft, will make the U.S. ASAT a considerably more capable weapon if deployed. The United States will be able to launch consecutive ASATs much more rapidly than the Soviets, who are restricted in how rapidly their ASAT can be fired by their limited number of launch sites and by the time required to recycle them. There are also significant asymmetries in the target sets which are at risk to the two systems. Many important space functions are carried out by the United States using satellites in geosynchronous orbit, well out of range of the Soviet ASAT. Many Soviet satellites with similar functions use highly elliptical "Molniya" orbits, which could be vulnerable to U.S. attack at their lower altitudes. However, the United States would face severe logistical and operational difficulties in attempting to exploit this vulnerability. In addition, since Soviet satellites are shorter lived than U.S. satellites and are consequently replaced more frequently, the Soviets may be better prepared to reconstitute space systems than the United States would be.

In spite of asymmetries in capability, neither the existing Soviet ASAT nor the U.S. ASAT undergoing tests poses a severe military threat to the other side. The present level of ASAT technology is significantly limited. Both U.S. and U.S.S.R. weapons are restricted to targets in low Earth orbit and cannot reach geosynchronous orbit. Both systems may have to wait several hours for a target satellite to come within range of the appropriate F-15 base (for the U.S. system) or ground launch site (for the Soviets), although the mobility of the F-15 makes this restriction considerably less severe for the U.S. ASAT. If either the U.S. or the U.S.S.R. system were mated to boosters able to reach geosynchronous orbit, the ascent would take many hours. In light of these limitations, many treaty proponents would tolerate (although not necessarily prefer) a treaty which would "grandfather" existing systems. Perceptions differed as to the relative political implications of the existing U.S.S.R. system versus the U.S. ASAT which is undergoing testing, but nobody felt that the overall military balance was affected significantly by either—especially when compared with potential future ASAT developments.

A ban on testing ASAT weapons would greatly increase the difficulty of developing a high-confidence, high-quality, dedicated ASAT system. Panelists thought it would be very difficult to develop and field a highly capable new system with no detectable tests. Some tests might go undetected—for example, there are many perfectly legitimate activities involving rendezvous in space which could be made to be partial tests of ASAT interception capability—but many tests would be required to instill confidence in an ASAT system, and some of these would probably be detected. Banning the tests would force the violator either to forgo tests or to test covertly; covert testing, assuming that it could in fact be carried out undetected, would certainly be more difficult

and less extensive than the overt testing that would be possible in the absence of a ban. In the absence of tests, all agreed that no one could be highly confident that a new system would be effective in difficult scenarios (against many targets in a short time interval and/or effective at geosynchronous altitude). If a system were to be developed without testing, the inability to make refinements based on tests and the lack of confidence developed through tests would degrade the system's military significance.

ASAT and ballistic missile defense (BMD) systems and technologies are closely related. As effective ASAT weapons are developed and introduced, boost-phase ballistic missile defense systems will become increasingly problematical since all such systems utilize space-based early warning systems and possibly other subsystems which would be vulnerable to ASAT attack. Many, although not all, prospective midcourse BMD systems would also have vulnerable space-based assets, and even terminal BMD systems would likely utilize space-based early-warning sensors. At the same time, even a poor quality or prototype midcourse or boost-phase BMD system may have very significant ASAT capability since satellites are much easier to destroy than missile warheads. Therefore, development of boost-phase and mid-course BMD systems will severely constrain ASAT arms control possibilities. Conversely, since ASAT and BMD technologies are related, treaties limiting ASAT development or testing will limit development and deployment of boost-phase and midcourse BMD systems. Of course, the 1972 ABM Treaty and 1974 protocol thereto already severely constrain testing, development, and deployment of BMD systems.

POINTS OF DISAGREEMENT

Disagreement over the desirability of an ASAT treaty hinges on basic philosophical differences over the role of arms control. Although acknowledged at the workshop, these differences were not discussed or debated significantly during the sessions. They are outlined below in an attempt to summarize some of the considerations most relevant to different sides of the ASAT arms control debate.

One attitude, supporting ASAT arms control, is that we value the safety of our own satellites more than we value the ability to destroy Soviet satellites. We want to protect those of our own military support functions which we presently carry out via satellites, and protecting them is much easier if our satellites are not threatened by a highly developed, highly capable Soviet ASAT. Preventing the Soviets from deploying an effective ASAT would be much more helpful than developing our own.

While a ban on all Soviet ASATs would be ideal, the principal U.S. interest is to prevent the Soviets from developing a highly capable system: one which works reliably, threatens satellites in geosynchronous orbit, operates with no warning, and/or attacks many targets at once. Several approaches, including banning ASAT testing, banning the development of new ASAT systems, or banning all dedicated ASAT systems, could inhibit such a Soviet development. Banning only tests or new developments would be more easily verified than banning all dedicated ASATs; however, a total ban might nevertheless be a more effective approach to preventing development of a highly capable Soviet system. Although no agreement can eliminate all ASAT capability, supporters of ASAT arms control felt that an agreement could be devised which would make Soviet development of such a highly capable ASAT system very difficult, and that such an agreement could be adequately verified. The criterion for supporting an agreement would be improvement in the security of our space systems as compared to not having an agreement.

A contrasting approach considers military competition between the United States and U.S.S.R. to be inevitable, with arms control in many cases not being an effective or appropriate alternative to that competition. Accordingly, the relevant measure of national security would be relative advantage or disadvantage of the United States with respect to the U.S.S.R. Those holding this view consider it essential to deny the enemy the use of space during a conflict when such use provides a military advantage. In the case of ASAT arms control, even if U.S. satellites were to be safer with an ASAT limitation or test ban than without one (which would almost certainly be the case), a treaty might not be appropriate if it would benefit the Soviet Union more than it would the United States. Such asymmetrical advantage might arise under an ASAT accord for two reasons: First, a treaty would divert the military competition away from an arena (ASAT competition) where the United States would otherwise have been able to exploit its superior ability to develop highly sophisticated technologies. Second, the Soviets might cheat. Because of the asymmetric nature of Soviet and American societies, it is argued, the Soviet Union is much more likely than the United States to cheat on an agreement. For the same reason, Soviet attempts to cheat are more likely to be successful. Whether or not the kinds of violations which might go undetected would in themselves pose major threats to U.S. security, any covert violation would work to our military disadvantage and would have undesirable political and psychological consequences as well.

There is disagreement regarding how much significance can be attributed to residual or covert ASAT capability. The panelists agreed that a considerable testing program is required in order to have high confidence in an ASAT system. However, there are differences of opinion regarding how significant an incompletely or covertly tested system might be. A covert system might not engender high confidence, it might not be as reliable as a dedicated, overtly tested system, and it might be discovered, but it might nevertheless still be developed. There is disagreement not only about how remote this possibility is, but also about how this possibility affects the relative advantages of a treaty versus the risks.

ASAT arms control is also complicated by more general considerations regarding the military use of space. On the one hand, emplacing weapons in space or using weapons against targets in space can be seen as breaking a de facto political taboo which would be difficult to restore. Furthermore, introducing weapons into space might make the world a more dangerous place; this is now almost universally believed to be the case concerning introduction of multiple independently targetable reentry vehicles (MIRVs). On the other hand, any space arms control might be viewed as a political and psychological barrier inhibiting the much wider exploration and exploitation of space as a theater of military operation. A primary example of the wider possibilities of space is ballistic missile defense—while many would not be willing to limit ASAT weapons at the price of impeding investigations into the possibilities of BMD, others see those restrictions on BMD which would be included in an ASAT accord as reinforcing the ABM treaty in support of its original and continuing goals.

TOPICS FOR FURTHER RESEARCH

Among the more general subject areas suggested to the workshop for further research were possibilities for "rules of the road" agreements in space. As noted above, many participants believed that some measures to reduce uncertainty and ambiguity in space might be desirable. Although possible models were proposed, potential agreements were not discussed in detail. What sort of mechanisms (be they unilateral actions, treaties, or informal working ar-

rangements) could be established to permit mutual U.S. and U.S.S.R. use of space with a minimum of suspicion?

Are there ways of characterizing ASATs such that we can define and ban the most threatening or destabilizing types? Certain activities in space are clearly more threatening than others, just as certain activities are more visible than others. Is there a way that a "rules of the road" agreement could focus on the more dangerous rather than the more visible? What are the implications for verification and for stability?

No treaty of any kind can be perfectly verified. Several questions arise in handling ASAT treaty provisions which must therefore be verifiable only partially, or with less than 100 percent confidence. One problem involves how general or specific treaty provisions must be made. Treaty language intended to prevent some particularly threatening activity (e.g., testing ASAT interceptors at geosynchronous orbit) might be phrased in general terms (e.g., forbidding all ASAT tests) which would include less threatening activities that might be less verifiable (e.g., testing ASATs in low earth orbit where they might be masked as non-ASAT-related operations). What are the implications of having varying levels of confidence in verifying compliance with treaty provisions? Are activities which are not explicitly proscribed under a treaty necessarily condoned?

Another verification issue requiring further work involves cooperative verification procedures. Although existing rules regarding freedom of navigation and innocent passage on the high seas permit forces of one country to approach those of another, approaching a foreign satellite closely enough to examine it in space might nevertheless not be taken kindly in the absence of prior approval. If nuclear weapons are to be kept out of space with high confidence, then cooperative inspection procedures (either in space or on the ground) will likely be required. Can such procedures be arranged?

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Opening Statement by Senator Larry Pressler

In the quarter-century since the launch of the first man-made satellites, the world has witnessed a quantum leap in the development of space-based and space-related technology. These developments have largely served peaceful purposes. We have learned to use satellite data in crop forecasting; space systems are today's key link for communications between nations; and by operating in space we may be able to solve our energy crisis and learn more about the universe in which we live. The military has also played a major role in space. To date, military space programs have enhanced global security and provided a principal method for arms control verification. No one can dispute that the military should sustain these efforts.

But as technology has improved our ability to operate in space, attention has turned towards using space as a new medium of warfare. We are no longer simply speaking of using space systems for reconnaissance, military communications, early warning and crisis management, but we are on the threshold of transforming space into the new field of battle.

Some would argue that this threshold has already been crossed. Indeed, for over 15 years the Soviet Union has operated an anti-satellite weapon. That weapon continues to be tested and its use against American satellites would seriously harm U.S. security.

In response to this deployment, the United States has developed and started to test a counter-ASAT. This American system will become operational in the latter half of this decade.

The ASAT problem is, however, only the forward edge of a potentially ominous trend in the military uses of space. The United States, and no doubt the Soviet Union, is starting a process that may lead to the deployment of beam-powered weapons capable of attacking a large number and a wide variety of targets in or flying through space, including ballistic missiles.

While I support the goals of removing the threat posed by nuclear weapons, it is far from clear that the move into space-based ballistic missile defenses will remove this threat. We must proceed with caution and engage in careful deliberation before beginning such an initiative. These futuristic weapons are certain to cost hundreds of billions of dollars. They may be ineffective and could complicate the task of providing for an effective national defense posture, while undermining strategic stability.

Given the potential costs and risks, I believe that the Congress must carefully consider both the strategic options and their arms control implications. For this reason, the Senate Foreign Relations Arms Control Subcommittee has held a series of hearings on the issue of arms control in space. Let me note that we began our deliberations long before ASAT and so-called "Star Wars" weapons received the serious attention given to them today. In consequence of these hearings, the Foreign Relations Committee favorably reported out S.J. Res. 129 which calls for a return to the negotiating table on ASATs, a moratorium of limited duration on ASAT space flight tests, and the inclusion of future space weapons technologies in these talks.

The hearings in the Arms Control Subcommittee provided Senators with a great deal of information in analyzing the implications of a space arms race and the arms control alternatives. But we continue to face many uncertainties and many questions remain unanswered. These issues must be quickly addressed if arms control is to be relevant to the problem. In addition, the Congress will soon have to decide whether to fund a multi-billion dollar research program on directed energy weapons. This workshop should allow us to continue the learning process begun in the Foreign Relations Committee.

I am, therefore, pleased that the Office of Technology Assessment has agreed to conduct

this workshop. Special thanks go to OTA Director Jack Gibbons and to workshop director Peter Sharfman for organizing this meeting. In addition, I want to thank this highly distinguished group of participants for coming to Washington to share their wisdom with us, particularly our workshop Chairman, McGeorge Bundy.

As I said, the Congress has a great deal to learn about space weapons and arms control. I am certain that this workshop will have an important role in our examination of these issues.

Overview

This workshop focused on anti-satellite weapons as an arena for arms control. Early in the first session, however, a panelist pointed out that such a focus in many ways creates an artificial distinction. Space holds a special "emotional allure." Much of the public debate concerning the militarization of space may result as much from that allure as from an informed judgement of the contribution of space activities to the military balance of power.

"Nuclear weapons and nuclear war remain the most important focus for arms control," a panelist pointed out. "ASAT arms control could reinforce nuclear arms control, but it could also divert attention from that central, overriding threat." At the same time, however, he and the remainder of the panel recognized that the appeal of space for military support operations is indeed high, and that the "allure of space" cannot be neglected in any discussion of ASAT arms control.

ORGANIZING DISCUSSION

Three ways of organizing discussion about ASATs were presented in the opening session. The first is to enumerate the various mechanisms of destroying satellites. There are essentially three distinct types: 1) direct interceptors, such as the current U.S. and Soviet ASAT weapons which home in on and then destroy target satellites; 2) "space mines," satellites which are stationed in orbit and later detonated to destroy nearby satellites; and 3) directed-energy weapons, which destroy satellites by delivering particle or radiation beams from a distance.

Other techniques such as concealment, spoofing, jamming, capturing control, and attacking ground stations, can disrupt the operation of a satellite. The difference between interfering with a satellite and permanently disabling it is significant, especially with respect to what is possible or desirable to regulate in a treaty. This distinction was made several times during the workshop.

A second method of organizing ASAT issues is to focus on the functions of potential target satellites and on the implications of subjecting these satellites to attack. So far, there are five primary roles for military support satellites—communications, surveillance and warning, navigation, meteorology, and geodetic survey. Different measures may be required to preserve each of these different functions in the presence of an ASAT threat.

A third organizational scheme is to enumerate anti-satellite attack scenarios and consider their effects on military capabilities and their prospects for escalation. Journal articles and press reports have discussed "just about every possible circumstance" involving anti-satellite activity, from tampering in peacetime to global nuclear war. Studying various possible scenarios has the advantage that, while ASAT technology can and will change, the scenarios for ASAT conflict may be more constant.

DISCUSSION FOCUSES

According to one panelist, the intersections or confluences of these three approaches—ASAT technologies, tempting or particularly threatening targets, and plausible circumstances—show the relevance of ASAT weapons and tactics to arms control. He singled out in the first workshop session several points about which further discussion could be fo-

cused. These issues, along with some items identified later in the workshop, are briefly described below and include:

RESIDUAL ASAT CAPABILITY

Many systems can destroy satellites besides those built or designed for that purpose. For example, ICBMs can be reprogrammed to attack satellites rather than terrestrial targets, giving both the U.S. and U.S.S.R. a de facto nuclear ASAT capability. The nuclear-armed Galosh anti-ballistic missile (ABM) interceptors, deployed by the Soviet Union around Moscow under the terms of the 1972 ABM Treaty, can easily destroy satellites passing overhead at altitudes lower than about 1,000 km. However, several panelists pointed out that the use of nuclear warheads against satellites is not plausible in situations short of nuclear war.

There is also nonnuclear residual capability. Rendezvous and docking procedures used in manned spaceflight could be applied to ASAT interception. With sufficient radar support, it is conceivable that Galosh interceptors having conventional warheads might be effective against satellites.

Since the above systems would remain even if all dedicated ASAT systems were banned, panelists agreed that residual ASAT capability will exist under any arms control regime. The more that space utilization and space technology develop, the greater the residual ASAT threat will become. Therefore, panelists strongly emphasized that no arms control agreement can replace the need to make the functions that we carry out in space survivable (see app. A). Functional survivability includes protection against non-ASAT threats, such as attacks on ground stations, and it does not require survival of all space assets. Space systems can be duplicated, and non-space-based alternatives for many support functions now done in space can be developed. Panelists noted that survivability would be easier to ensure if dedicated ASAT systems, especially highly threatening future ones, were controlled.

Determining the level and effectiveness of residual ASAT capability is important to weighing the desirability of any treaty. An ineffective ASAT which had no more capability than the residual capability of non-ASAT systems would not significantly increase the threat these non-ASAT systems potentially pose to satellites. There is, then, some minimum level of capability that an ASAT weapon would have to exceed before its existence would be significant. It would make little sense for an ASAT treaty to require a level of verification holding ASAT capability far below this minimum. However, exactly where this minimum level is located is a highly debatable point. Panelists who felt that the residual capability of non-ASAT systems was quite significant questioned the value of negotiating any limit to dedicated ASATs at all. The level of residual ASAT capability was discussed further in the verification session of the workshop.

COMPARISON OF U.S. AND U.S.S.R. ASAT WEAPONS

Although this topic is unavoidable in any discussion of ASATs, several panelists warned against overemphasizing the two countries' respective capabilities in isolation, without simultaneously considering their respective target sets and possible scenarios.

Both U.S. and U.S.S.R. weapons are designed to intercept target satellites using a three-step procedure. First, ground-based sensors identify the target satellite and determine its orbit. Next, the interceptor is launched and guided towards the intercept point, and finally, the interceptor's homing sensors are activated and it closes in on the target satellite. However, while the U.S. air-launched ASAT climbs directly towards its target satellite in ten or twenty minutes, the Soviet ground-launched ASAT must roughly match orbits with its target, a process which has taken up to several hours in tests.

The range of the booster and the homing process determine which target orbits an ASAT weapon can threaten. The U.S. Miniature Homing Vehicle (MHV) ASAT weapon now undergoing testing destroys its target by direct impact and can home in on its target from a wide range of directions. It needs only to get to the same place at the same time as its target, and does not need to match orbits with that target. The present generation of Soviet ASATs, on the other hand, is co-orbital—it needs to be in the same place at the same time traveling roughly in the same direction at the same speed as its target. So far, all Soviet ASAT tests have been conducted against targets in orbits with inclination angles near 65 degrees.

Workshop panelists felt it "beyond doubt" that the U.S. air-launched approach is "clearly superior" to the Soviet ground-launched technique. Besides the limitation of having to share its target's orbit, the Soviet ASAT is restricted by the small number of launch sites that can handle its modified SS-9 booster. As many as twelve hours might be required, while the Earth turns under the target orbit, to bring the target within range of a launch site. The Soviets are further limited by the recycle time of each launch pad, and they cannot launch many ASATs in rapid succession. U.S. air-launched ASAT interceptors can be launched much more rapidly, and from a much wider geographic area, than the Soviet ground-launched ASAT. The advantages of the U.S. ASAT's airplane-launched approach, and its direct homing interception, more than compensate for its altitude limit, which has not been released by the Air Force but was estimated by a panelist to be considerably lower than that of the Soviet ASAT. Although present U.S. plans call for ASAT-equipped F-15 squadrons having the associated logistical support to be based only at two sites within the continental United States, the planes and the associated support structure could be based in other areas to give even wider geographic coverage and more immediate response.

Another important asymmetry between near-term U.S. and U.S.S.R. ASAT capabilities is the target sets which each weapon will face. Many critical functions which the United States performs in space are carried out by satellites in geosynchronous orbit, far out of range of the Soviet ASAT. Similar functions for the U.S.S.R. are in many cases carried out by satellites in highly elliptical "Molniya" orbits, which could be vulnerable to U.S. attack at their lower altitudes. Present plans for deploying ASAT-equipped squadrons within the continental United States would not permit such attacks, but suitably equipped planes might be able to attack these Soviet satellites if they, and the appropriate logistical support, were based in the Southern Hemisphere. Even assuming appropriate bases could be obtained, in-flight refueling would be required.

Countering the potential advantages of the United States system is that it is still undergoing preliminary testing, whereas the Soviet ASAT has been tested, in a restricted manner, about twenty times over the last 16 years. The U.S. Department of Defense considers the Soviet ASAT to be operational. A panelist warned against comparing something that is "technologically possible that one side doesn't have" against an opposing system which "perhaps looks a little bit like a turkey" but in fact does have some capability. At any rate, no one doubted that the U.S. system could be made operational within a few years at most.

MILITARY ROLE IN SPACE

Much of the concern about ASATs and ASAT arms control deals with the role of satellites in military activities and the corresponding threat to military capability posed by ASAT weapons. Space systems are used extensively for military support, but satellites do not now fill a crucial, indispensable, and irreplaceable role. Many functions now carried out in space can be performed by other means. A paradox arises in that, to the extent that ASAT arms control masks the intrinsic vulnerability of satellites, alternatives to space systems may not seem necessary and satellites will be increasingly relied upon. If space utilization grows, so will the incentive to build

ASAT weapons. The solution is for arms control, if pursued, to supplement satellite survivability and redundancy programs and not to replace them. This point was repeated throughout the workshop: ASAT arms control cannot be a substitute for protecting and duplicating satellite functions.

ASAT ATTACK SCENARIOS AND POTENTIAL FOR ESCALATION

Does ASAT attack have a unique potential for triggering wider conflict? Does it imply that future conflict might be restricted to space? These points stimulated considerable discussion, but the panel doubted both.

Since military satellites are used principally for support activities, they don't functionally differ from terrestrial support systems. "Is the sinking of a U.S. intelligence ship not as likely and as inflammatory in a crisis as interception of a U.S. spy satellite?" questioned one panelist. Another panelist pointed out that "war in space cannot at all be separated from war on Earth." In any conflict, each side has certain objectives, and they are on the ground. "You don't shoot satellites just for the fun of it."

Other participants pointed out, though, that an ASAT attack might be less provocative than a terrestrial attack since people would not be directly threatened. "Maybe you destroy the 'allure of space'," said a panelist, "but you don't kill anybody." One panel member stressed that one cannot dismiss isolated ASAT scenarios to consider ASAT attack only in the context of a wider conflict. "I am skeptical about that because the United States has worked as hard as it possibly can to make itself extraordinarily vulnerable" to a low-level ASAT attack. "We have nothing in the pipeline to replace anything that's in space."

One panelist stated that the most worrisome ASAT scenarios involve low-level conflicts. In desperate cases, even a party not having a dedicated ASAT weapon might be tempted to attack an opposing satellite with whatever means could be arranged on the spur of the moment. In a low-level crisis which had not yet escalated to such a stage, however, existence or lack of a dedicated ASAT able to intercept with high confidence a threatening satellite might make the difference between attacking and not attacking. Carrying out such an attack "would be a tremendous temptation if it were easy to do so and could be done quickly and precisely and with very low collateral damage," even with the attendant risk of escalation.

Another panelist disagreed, maintaining that having fewer or poorer weapons does not necessarily lower the probability of their use. If a power feels that conditions warrant an attack on a satellite, it will be as likely to carry out that attack if it has one weapon as if it has 100. A decision of that magnitude will be a response to many internal and external pressures. "It isn't going to happen by itself," and if it is deemed to be necessary it may as likely happen with an improvised system as with a dedicated one.

An ASAT attack scenario which has been widely discussed involves attacks on the satellite-borne sensors that provide the U.S. early warning of a Soviet first strike. One participant minimized the importance or plausibility of such an attack scenario. A Soviet attack on warning sensors to prevent a preemptive or "launch-under-attack" U.S. strike might instead trigger that strike. So, if it were not to reveal an imminent Soviet nuclear attack, any Soviet ASAT attack would have to be nearly simultaneous with the launch of the ICBMs that it was intended to mask. Since any direct-intercept ASAT would take several hours to climb to the U.S. early warning sensors at geosynchronous altitude (no existing ASAT is presently capable of getting that far), only yet-to-be-developed directed-energy weapons or pre-emplaced space mines would present a significant threat in this scenario.

At any rate, the United States does not rely solely on early-warning satellites for notification of impending attack. Ground-based radars provide a backup, and for submarine-

launched missiles they give negligibly less warning time than space-based sensors. Ground-based radars can also be supplemented by ship-borne, air-borne, and rocket-borne sensors.

CONNECTIONS BETWEEN ASAT AND BALLISTIC MISSILE DEFENSE

There are quite significant strategic and technological links between anti-satellite weapons and ballistic missile defense (BMD) systems. ASAT issues are central to BMD, and while consideration of BMD is less crucial to analysis of ASAT per se, the two subjects have significant overlap.

One connection is that any effective BMD (except for local, low-altitude site-defense systems) is an even more effective anti-satellite weapon. Even a poor BMD can have significant ASAT capability since satellites are much easier to destroy than missile reentry vehicles (RVs). A system used for ASAT would face at most a few dozen targets, and therefore could take much more time to attack a satellite than a system used for BMD could allocate to each of the up to 1,000 ICBMs or thousands of warheads in a massive attack. Satellites are intrinsically more vulnerable to damage than are RVs, and in a great many ASAT scenarios, attacks on satellites would take place in a much less hostile environment than the nuclear war in which a BMD would have to operate. Furthermore, an orbiting satellite's trajectory is completely predictable, except for limited maneuvers, making a satellite in effect a fixed target.

A second link between ASAT and BMD is that BMD systems (again with the possible exception of local site-defense systems) have space-based elements which would be vulnerable to ASAT attack. Even if a BMD system did not use weapons based in space, it would likely have space-based sensors and communications links; any BMD system intended to attack ICBMs during their boost phase necessarily would require space-based sensors to detect missile launch. If BMD weapons systems were put in orbit, they would be ideal targets for each other. They would be large, expensive, and hard to miss. All indications at present are that space-based weapons would be much cheaper to destroy than to replace "probably by a factor of 10. Right now it looks like a factor of 1,000." On the other hand, they might be capable of self-defense once they became operational.

As ASAT technology is perfected, it will become increasingly unrealistic to deploy "anything that's space-based and expensive." Conversely, if BMD technology is significantly developed, it will severely constrain the possibilities for ASAT arms control, but it might also elevate strongly the incentive for ASAT arms control.

PROSPECTS FOR VERIFICATION

The issue of verifying compliance with an ASAT accord occupied much of the later workshop sessions. Panelists agreed that a total ban on **anything** having any ASAT capability would be both infeasible and unrealistic considering that residual ASAT capability (ICBMs, manned spacecraft, etc.) will invariably remain even if all **dedicated** ASAT systems are banned. There was also considerable agreement, though, that the extensive testing program necessary to develop and acquire confidence in an advanced ASAT weapon would almost certainly be detectable, and that a ban on such testing would require less extensive verification measures than a ban on possession. These issues are discussed further elsewhere in this report (p. 39 ff.).

"RULES OF THE ROAD"

Another important point developed in later sessions was the concept of "Rules of the Road" or "Utilization of Space" agreements. Whether or not some agreement limiting ASAT weapons or testing is desired or implemented, panelists saw a use for an agreement between the United States and U.S.S.R. which would allow each party to continue its use of

space without unnecessarily threatening the other. The United States and U.S.S.R. are each likely to conduct space activities which will appear provocative to the other, and some arrangements for reducing uncertainty might be helpful. The form of such an agreement was not discussed in detail; some additional discussion is reviewed in later sections of this report.

PRESENT TECHNOLOGY

The panel agreed that present ASAT technology (both Soviet and U.S.) is limited in significant ways, and that developing systems free of these limitations would require testing programs which would almost certainly be observable. Both existing systems (the Soviet system and the U.S. system undergoing tests) are only capable of reaching low earth orbit (on the order of 1,000 km)—neither can reach important satellites located at geosynchronous orbit (36,000 km). Both systems have inherent time delays, in waiting for targets to come within range of the launch site and in reaching their targets once launched. (The U.S. system, however, is significantly less constrained in these respects.) Both systems leave intact the adversary's ability to launch ASATs. There was general agreement that present ASAT weapons are much less threatening, and much less destabilizing, than what could be deployed in a new generation of ASATs, including ones which could attack many targets promptly and which could reach geosynchronous orbit.

As an example, one panelist posed the case of both the United States and U.S.S.R. having constellations of space-based beam weapons. As mentioned previously, such systems would likely be targeted at each other. Whichever side attacked first would not only retain its own ASAT (or BMD) capability but would eliminate its opponent's. This extreme incentive to attack first would be highly destabilizing.

Another participant took issue with this scenario, stating that the systems would likely operate so that such an attack by one side would result in most of both constellations being destroyed. For instance, one party detecting an attack could detonate space mines trailing its opponent's systems. All panelists agreed, however, that the present systems are not as threatening as future ones could be.

Descriptions, Pros, and Cons of Possible Agreements

FOCUSES AND PHILOSOPHIES

Before the United States undertakes to negotiate a treaty, it must determine that a treaty would be desirable. Could there be a treaty which would be in our interest, recognizing that Soviet interests do not coincide with our own? We then need to ask whether such a treaty might also be in the Soviet interest. If not, it is pointless to continue. It is not sufficient to find a single set of actors on each side that would be in favor of a treaty. In order to be acceptable, a treaty must be desirable to a large number of players on each side.

Early in the workshop, a panelist questioned whether anti-satellite weapons were indeed an appropriate focus for arms control. He pointed out that the technology and concepts are still being developed. Furthermore, given that some residual ASAT capability will always exist, one can't deny a country the ability to destroy satellites. Although an ASAT arms control accord might include some desirable features, the panelist felt that those goals might better be pursued in association with other arms control ventures.

Another panelist stated that an ASAT agreement would greatly increase the security of our satellites by limiting the development of new ASATs that could be considerably more sophisticated than the present systems. Such an agreement would make the task of protecting our satellites much easier. We must compare the residual ASAT capability under a treaty with the threat to our satellites in an all-out ASAT competition, he pointed out.

One panelist felt that we should be seeking a stable stopping point to the ASAT competition, or at least some intermediate points that would slow down the race, reduce tensions, and lend themselves to further negotiation. In particular, some concern was expressed about the U.S. ASAT being deployed without sufficient consideration of its long-term or possibly irreversible implications. An interim accord would provide some time.

Many participants supported the idea of finding ways to prevent "provocative and inflammatory" activities in space. Panelists realized that both the United States and the Soviet Union will continue to utilize space in ways which might have great potential for creating uncertainty and misunderstandings. This possibility could be mitigated by an arms control agreement. "Survivability is not the only goal" of a space arms control agreement, suggested a panelist, "and in my mind not even the main goal." He explained that the case for arms control really rests on the Soviets' desire to come to some working agreement with us so we both can develop space capabilities "without coming to clashes or crises or problems." This panelist supported a "rules of the road" agreement which would "provide some limit on activities which are going to pose major puzzles" to both the United States and the U.S.S.R. This form of agreement might or might not include an ASAT ban.

We and the Soviets tend to legislate the norms of international conduct by our actions and our agreements, noted a participant. In this manner, we have, for example, in effect declared that "offensive nuclear weapons are okay to have," but that "they're not okay to use directly in a threatening manner in crises." Regarding anti-satellite activity, we have so far "pretty much legislated that it's okay to live and let live in space."

"An ASAT treaty," he continued, "ought to reinforce that healthy kind of approach to space."

PHILOSOPHICAL DIFFERENCES

A point which was readily recognized at the workshop, but was not discussed or debated in depth, was that disagreement about the value of an ASAT accord stems from deeper philosophical differences about arms control in general.

Putting it a little simplistically, treaty proponents feel that our national security will be better with an ASAT treaty than without one, and that such a treaty can be verified well enough to ensure our security. Treaty opponents, on the other hand, focus on possible asymmetries in the relative costs and benefits of a treaty to the United States and to the Soviet Union. The Soviet Union, they feel, would benefit more from United States compliance than the United States would benefit from Soviet adherence with possible cheating. They feel that arms control is appropriate only if it would be advantageous to the U.S. in spite of this inherent asymmetry.

Is the criterion for negotiation that we end up better with a treaty than without one? Or, is it rather that our position with respect to the Soviets be better with a treaty than without one? Similarly, there are differences in overall attitudes concerning space and space arms control. Some view deployment of space-based or space-directed weapons as the breaking of a de facto political taboo, which would not only make the world more dangerous but would also be difficult to reverse. Alternatively, any space arms control treaty could be seen as a political and psychological barrier to the wider exploration and exploitation of space as a theater of military operation.

ASAT LIMITATION TREATIES

In discussing possible forms of ASAT arms control, the panel categorized five types of ASAT arms control agreements:

1. Bans on all testing, use, and possession of all ASAT capability.
2. Bans on all testing, use, and possession of dedicated ASATs.
3. Bans on use and testing, but not possession, of dedicated ASATs.
4. Bans on development or use of new types of ASATs; no restrictions on existing ASAT systems.
5. Bans on use of ASATs; no restrictions on possession or testing.

Panelists readily agreed that the first type of agreement is unattainable. Some non-ASAT systems have some capability to serve as ASATs, so residual capability would remain even if dedicated ASAT systems were banned. Recognizing this fact, the second type of agreement would deal only with dedicated, and presumably more threatening, ASAT systems.

Most of the workshop discussion about ASAT limitations involved a testing ban which might or might not include existing systems and which might or might not prohibit ASAT possession. Testing of a dedicated ASAT weapon would be more visible, and less ambiguous, than its possession. To avoid some of the difficulties of a more extensive ban, a treaty could permit possession of ASATs but ban use and testing. Without testing, the significance of possible ASAT possession might decrease with time. In the view of some, new systems could not be relied upon, and confidence in existing systems would slowly degrade.

The fourth type of agreement, conceding the existence and operation of existing systems, would still restrict the deployment of new and more threatening ASATs. It would also suppress the question of residual ASAT capability, since if both sides had a dedicated system it is unlikely that either would use "baling-wire" systems. Considering the disparity between the U.S. and the Soviet ASATs, though,

several panelists felt that the Soviets might not be willing to concede to the United States the right to test and deploy the air-launched MHV ASAT without reserving the right to develop a system at least as effective.

The fifth type of agreement in the above list would prohibit the use of ASAT weapons and might also delineate acceptable behavior by codifying some set of "rules of the road." Such measures attracted much interest among the panelists as supplements to, as well as alternatives to, ASAT limitations. Proposed agreements of this sort are not as well defined as prohibitions of ASAT testing or possession, for which draft treaties have been prepared by various parties.

ASAT ARMS CONTROL: PRO ARGUMENTS

ASAT treaty proponents see an ASAT arms race as not serving our best interests. "The burden is always on arms control to explain how the world is going to be better with the treaty than without," remarked a panelist, "and the burden is never on the person who just wants to keep blundering ahead to explain how the world is going to be safer that way." Treaty proponents see continued ASAT competition as unwise, and believe that a treaty would be worthwhile even if it served only to constrain future developments. Observing that the ASAT problem will not disappear completely, with or without a treaty, one panelist noted that "in the absence of restrictions, the problem is going to get a great deal worse."

Offense Dominance.—An ASAT race is not desirable because, for the foreseeable future, the offense will always win. Satellites are expensive, and they are inherently vulnerable because of their known trajectories, their limited numbers, and their fragility. Significant cost and performance tradeoffs are required to protect satellites against attack. Therefore, U.S. satellites are likely to be much cheaper to destroy than to replace. This balance will not be changed by deployment of a U.S. ASAT weapon, even if it is superior to the Soviet ASAT. Assuming that we need our own satellites much more than we need to attack Soviet satellites, treaty proponents believe that we should attempt to negotiate a mutual limitation on ASATs.

Defense and Possible Future Developments.—Arms control proponents particularly saw great value in ending the ASAT competition as soon as possible. Current technologies are relatively primitive compared to future possibilities, which could be very threatening. It is easier to protect satellites against the current threat than against subsequent generations of ASATs. The later that action is taken, the more systems will be deployed, the more complicated the technology will become, and the more difficult compliance with any treaty will be to verify. Adequately verifiable testing bans are possible, proponents feel, and they would severely limit the development of truly threatening anti-satellite weapons. The ASAT competition has not progressed so far that stopping now would be irrelevant.

We are now at a stage in which only our low-altitude satellites might be vulnerable, and we face the quite possible future alternative of having our entire in-orbit force structure subject to prompt destruction. Directed-energy ASAT weapons, for example, will very likely be deployed if there is no ASAT accord. Such weapons, having long ranges and near-instantaneous reaction times, would be destabilizing—especially if based in space. If such systems were developed by either or both sides, they would be tempting targets, and each side would have great incentive to attack first in order to disarm its opponent. In the absence of an ASAT accord, we are also likely to see the advent of space mines, which could be comparatively inexpensive. If space mines were widely deployed, most or all of our important satellites would be subject to almost instantaneous destruction.

Existing Unreliability.—Future ASATs will likely be much more reliable than the present systems, which has significant implications for stability. Neither the existing Soviet ASAT nor the U.S. ASAT under development can presently be considered highly reliable. The

U.S. weapon has never been tested against a target in space. According to published reports, the Soviet weapon has not functioned properly in a significant percentage of its tests. Some panelists did note, however, that without knowing the nature of and responses to these failures, we can not necessarily infer a reduced confidence or lower reliability of the Soviet ASAT.

Highly reliable ASATs, if they existed, might increase the risk that low-level crises would escalate. As discussed in the overview, confidence in the ability to attack a threatening satellite easily, quickly, and precisely may increase the likelihood of doing so. In a tense situation, posited one panelist, the United States or the U.S.S.R. might initiate ASAT conflict by reasoning "we're not going to kill anybody; we're not going to threaten anybody's strategic warning system, but nobody's going to take pictures of us for a few weeks now." Both the temptation and the danger of an ASAT attack against a reconnaissance satellite in a crisis would be "extraordinarily high."

Economic Pressure.—A panelist noted that ASAT limitations could forestall utilization of ASAT competition by the Soviets as a relatively low-cost means of applying pressure to the United States. Perceiving a full-scale military buildup by the United States, but constrained by the performance of their own economy, the Soviet political leadership may seek ways to pressure the United States without having to engage in an across-the-board response. In most cases, the development, or improvement, of an ASAT system is much cheaper than protecting against ASATs by duplicating or supplementing space assets.

Mutual Benefit to Treaty.—ASAT arms control advocates noted that ASAT arms control negotiations are not a "zero-sum" game. Both the United States and the Soviets would benefit from an ASAT accord. Soviet interest in negotiations does not mean that we must a priori oppose them. "Certainly you can't expect the Soviet Union to sign any agreement which works to their net disadvantage," explained a panelist, "but most people regard the elimination of nuclear war, or even the significant delay, decade by decade, of all-out nuclear war, as being to the advantage of the Soviet Union as well as the United States."

Private Sector Concerns.—One argument which has been made in favor of ASAT arms control found no support at the workshop. In the past, it had been argued that without an ASAT accord, private industry would be reluctant to invest in space systems which are inherently vulnerable to ASAT attack. Panelists pointed out that the Soviet's current capability to destroy anything in the United States or at sea has not affected the private sector. They noted, as an example, that the Soviet ability to shoot down airliners "which has been demonstrated" has not affected airline investment decisions.

A concern of private industry which was backed up at the workshop is the problem of space debris from ASAT weapons test. Studies mentioned at the workshop indicate that a significant source of debris in low-altitude orbit is Soviet ASAT testing and ASAT-related activity. ASAT tests at or near geosynchronous orbit would be of considerable concern to communications satellite companies.

ASAT ARMS CONTROL: CON ARGUMENTS

Much opposition to ASAT treaty efforts stems not from the desire to have ASAT weapons but rather from the viewpoint that arms control is not an effective or appropriate means of addressing the ASAT question.

Residual ASAT.—ASAT treaty opponents raised the problem of residual ASAT capability—means for destroying satellites which would be infeasible or unrealistic to eliminate by any form of agreement. They also noted that methods for interfering with the operation of systems using satellites, short of destroying them (jamming, spoofing, or attacking ground stations or support facilities), might be difficult to address in an ASAT arms control accord.

Asymmetric Societies.—The asymmetrical nature of the Soviet and the U.S. societies, according to arms control opponents, implies that there will be asymmetric advantage from any symmetric treaty. The Soviets are much more likely than the United States to cheat on an agreement, and if they do cheat they are much more likely to get away with it. Furthermore, there seem to be differences between the United States and the Soviet Union in interpretation of "borderline" activities—"I think we have learned over the last twenty years that the way the Soviet Union keeps a treaty is not exactly the way two-thirds of the Senate had in mind," summed up one participant.

Verification.—Treaty opponents are very concerned about the verifiability of compliance with an ASAT accord. No treaty, of course, is perfectly verifiable, but different people assess differently the likelihood (or significance) of activities which may escape detection. Inventories of ASAT interceptors on the ground or the contents of satellites in space may be difficult to monitor. Compliance with bans on ASAT interceptor testing may be difficult to verify since there are many legitimate activities requiring rendezvous in space which could be made to be partial tests of ASAT interception capability. Furthermore, even a small amount of Soviet cheating in an ASAT arms control agreement could be significant since U.S. satellites are long-lived, valuable, and limited in number. We would be more sensitive to loss of a few satellites than the Soviets, whose satellites have shorter lifetimes and are consequently replaced more frequently.

Limits on U.S. Strengths.—More general objections to ASAT arms control result from the constraints it would put on the ability of the United States to exploit its technological expertise. By permitting the Soviets to "make up lost time" in developing advanced ASAT technology, said a panelist, ASAT arms control would "allow the Soviets a major competitive advantage."

Both the United States and the Soviet Union have too great an interest in the military use of space to agree to an ASAT treaty that would deny the ability to engage in conflict there, he explained. "If there is conflict, there is going to be conflict in and from space. It's inevitable because of what we've been doing for about the last twenty years" by putting very valuable systems in space and using them to the extent that we do.

Ballistic Missile Defense. Another very significant source of opposition to ASAT arms control is the desire to investigate advanced ballistic missile defense technologies. Some of the concepts most attractive to BMD supporters involve "boost-phase" defenses which attack missiles as they climb out of the atmosphere. However, since effective boost-phase weapons would likely also be effective against satellites, they would almost certainly have to be restricted under an ASAT accord which limited the most threatening ASAT technologies. Systems capable of doing boost-phase BMD would be inconsistent with the existing 1972 ABM treaty, but supporters of BMD research may not wish to contend with a restrictive ASAT accord as well. An opinion expressed at the workshop was that "the ABM treaty is bad enough to have as a complicating factor in any type of transition towards strategic defense without adding a layer of porous ASAT agreement."

Difficulty.—A more pragmatic reason for opposing ASAT arms control is that the process of negotiating such a treaty with the involved executive agencies, with the Soviets, and with the Congress is "incredibly painful" and not worth undertaking in the absence of an overwhelming conviction that it would be in the national interest.

ASAT WEAPON: PRO ARGUMENTS

Those opposing an ASAT treaty believe that ASAT arms control is not in the national interest. They may also believe that having an ASAT weapon is in the national interest. Anti-ASAT treaty arguments and pro-ASAT weapon arguments, although related, are distinct.

Three justifications for developing anti-satellite weapons were reviewed at the workshop. Of the three, one was mentioned but not discussed in detail, and another was not supported by ASAT proponents on the panel.

Attack Hostile Satellites.—The primary reason for developing an American ASAT weapon is to deny the use of space to an adversary during conflict. The particular example cited by administration officials and by workshop participants is the threat posed by Soviet ocean reconnaissance satellites which are said to be able to locate U.S. Navy ships on the high seas. Those holding this view do not wish to allow the Soviets freedom to conduct reconnaissance activities from space which threaten American forces. They also expect that the Soviets will utilize other space assets for improving the effectiveness of their military forces ("force-multiplication") and want to be able to deny the Soviets these capabilities as well.

An American ASAT weapon could be stabilizing, it was argued, if used against Soviet reconnaissance satellites which would otherwise be available for retargeting Soviet missiles. In a "shoot-look-shoot" scenario, Soviet reconnaissance satellites would be used to locate U.S. military targets that had survived a first strike. This data would be used to retarget a Soviet reserve force to destroy those remaining targets. The Soviets likely know that they would probably need "more than one echelon of strategic attack" to carry out an effective strike against the United States homeland, argued a panelist. Denying them this "shoot-look-shoot" capability would make it harder to conduct an effective first strike, lessening its probability and therefore increasing stability.

Support Negotiations.—A second reason mentioned at the workshop for developing a U.S. ASAT weapon would be use as a "bargaining chip" to induce the Soviets to negotiate an ASAT treaty. Whether or not this viewpoint may motivate development of some weapons systems, it does not properly belong in a tabulation of "pro-weapon" arguments. If one seeks to negotiate a ban on ASAT weapons, for example, then one presumably has already determined that having an ASAT weapon is not necessary.

Deterrence.—The third reason given for having an ASAT weapon is to deter ASAT attack. This rationale was not supported at the workshop. Arms control supporters and opponents both felt that the ability to retaliate against terrestrial targets served to deter ASAT attack at least as well as the ability to retaliate against satellites. Satellites can be protected against ASAT attack in a number of ways, and having the capability to respond in kind was not thought to be singularly effective in protecting satellites.

A panelist also pointed out that the deterrent role of an ASAT is in opposition with, not in support of, the role of eliminating hostile satellites. If an ASAT capability is required in order to support objectives (such as preventing detection of naval surface units by Soviet satellites) which are unrelated to retaliation, then the deterrent value of an ASAT must be balanced against its potential use in initiating space conflict to attack hostile satellites.

"RULES OF THE ROAD"

Many panelists, including supporters of ASAT limitations as well as those questioning the effectiveness or utility of ASAT bans, agreed that some sort of international agreement concerning "rules of the road in space" could be beneficial. These rules could also include rules on space-related ground activities. While the nature of such an agreement was left vague, and the negotiation process which might conclude in such an agreement was not analyzed, several motivations and possible examples for such an agreement were raised.

Rules of the road would try to alleviate situations which either side would consider particularly dangerous. For example, they might inhibit effective placement of space mines by establishing a minimum separation between satellites. As both sides continue their operations in space, such rules may become increasingly valuable.

One of the functions of a regime of rules in space would be to reduce instances where seemingly dangerous activities are observed without the means of finding out exactly what is going on. Certain activities which might be provocative could be prohibited, or they might be required to be accompanied by an explanation, perhaps in advance, which had some basis for being believable. The most important function of such an agreement, suggested one panelist, might be the establishment of a forum where questionable activities could be discussed. That the forum would help maintain an ongoing dialogue between the United States and the U.S.S.R. would be healthy in and of itself. Alternatively, said another panelist, it would be nice to know that if the Soviets do something that we find very threatening, they did it on purpose. "We might still find ourselves getting dangerously close to a war, but at least we would know better where we stood." A panelist also pointed out that besides defining acceptable conduct, "rules of the road" might also give some basis for responding to certain violations.

A precedent for "rules of the road" is the ban in the 1972 ABM Treaty prohibiting interference with the national technical means used by each side to verify compliance with that treaty. This measure is a "function ban": it does not refer to satellites or space in particular, but rather prohibits interfering with the function of verification. Such a function ban might be extended by building upon the example of the 1971 "Agreement on Measures to Reduce the Risk of Outbreak of Nuclear War," which requires the United States and the U.S.S.R. to notify each other "in the event of signs of interference with [early warning systems] or with related communications facilities, if such occurrences could create a risk of outbreak of nuclear war." This clause could be strengthened to prohibit interference with the function of early warning in general without reference to satellites or ASATs. A very important motivation for rules of the road would be the recognition, such as that implicit in the 1971 Measures Agreement, that accidents will happen.

An additional model could be the international regime existing on the high seas, in which certain particularly hostile and dangerous activities have been banned. Similar bans could be applied to space activities. However, since the "rules of the road" on the high seas as they currently exist do not keep ships out of lethal range of each other, similar rules would not be sufficient to ban space mines. New measures would be required if it were desired to eliminate the threat of space mines by keeping satellites apart by more than a lethal distance.

"Rules of the road will not prevent ASAT attacks," pointed out one panelist. "Perhaps they can't even be verified very well. . . . Nevertheless, an agreement along those lines might be worth having precisely because it would reduce ambiguous acts" and minimize the chances of escalation or misunderstanding in a crisis. Panelists agreed that "rules of the road" would not require an ASAT ban; some of those supporting an ASAT accord felt that it would be strengthened by rules of the road; those opposed to an ASAT agreement saw merit in rules of the road as an alternative.

All panelists agreed that the Soviets are increasing their utilization of space, including their development of ASAT capability. That fact, taken with their willingness to negotiate space arms control with the United States, can be seen as indicating that they would like to jointly draw up some general rules of behavior. "If that's the signal, that's a very interesting signal," interpreted a panelist. "It makes it that much more useful to look for ASAT treaties that simply have the merit of putting some kind of terms of agreement on record, if nothing more."

GENERAL DISCUSSION

There was no agreement on how much the ASAT threat would be reduced by a treaty, or on the significance and likelihood of residual or covert ASAT activity. An important point is the extent to which residual, possibly covert, ASAT systems would place our spacecraft at risk under a treaty regime. "Is it going to be closer to one-eighth of the original threat or is it going to be closer to seven-eighths?" asked one participant.

GRANDFATHERING EXISTING SYSTEMS

The discussion of possible ASAT limitations, their advantages, and their disadvantages touched on a number of issues. One of these was the question of "grandfathering" existing ASAT systems: Should the Soviets be permitted to keep their system? Should the United States be permitted to continue developing its own? One panelist felt strongly that the objective of a treaty is to prevent the development of technologies and capabilities which are much more threatening than those existing now. Such a treaty would block the "sustained, organizational effort" required to implement such advances in ASAT technology. Existing systems, which are not nearly as threatening as future ones could be, might be grandfathered in such a treaty. Alternatively, further testing and development of existing systems could be banned, especially at higher orbits.

One panelist felt that the Soviets would not accept an agreement which would permit existing systems because of the asymmetries in capability between the U.S. and U.S.S.R. ASATs. The U.S. F-15 system, a far more capable weapon, will be able to destroy Soviet satellites much more rapidly than they could be replaced and would be sufficient to deny the Soviets access to low earth orbit for a considerable period of time. Given the Soviets' present technique for attaining higher orbits by using lower altitude parking orbits, the U.S. ASAT could effectively deny the Soviets the ability to reconstitute higher orbit systems as well.

Another panelist was skeptical about negotiating away the Soviet ASAT because of the measures that would be required to give the United States assurance that it had been dismantled. The Soviets have "only in a sort of Aesopian way" admitted that the present SS-9 based ASAT exists at all, he said, "which is not a hopeful way to start out on the negotiation" concerning the "extraordinary measures" required to ensure that the system had been dismantled. However, if the Soviet ASAT is neither eliminated nor balanced with a symmetrical U.S. capability, then the political viability of any ASAT accord in this country would be "very, very low."

U.S. ASAT REQUIREMENT

Another issue stimulating considerable discussion was the need for a U.S. ASAT weapon. There was widespread disagreement about the requirement for an American ASAT to deny the Soviets the ability to target the U.S. fleet with their ocean reconnaissance satellites. There were no panelists with Navy backgrounds ("we've been sinking the Navy without its representation," noted a participant), but at any rate there was little support for the position that the Radar Ocean Reconnaissance Satellite (RORSAT) is an extremely threatening system. The capability to destroy Soviet reconnaissance satellites is neither necessary nor sufficient to protect the U.S. fleet, it was pointed out. The United States has many ways to deny the Soviets intelligence from these satellites—RORSATs are vulnerable to a variety of electronic countermeasures. Studies made more than 10 years ago laid out a "long laundry list of things that could be done other than blowing it up," such as decoying and jamming.

Furthermore, there are many ways the Soviets can locate American ships without the use of RORSATs. "For instance, they can ask

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their own ships, which accompany our aircraft carriers," pointed out a panelist. "If they didn't have radar ocean reconnaissance satellites, they would have other things."

Also disputed was the argument that a U.S. ASAT would be stabilizing since it would deny the Soviets the ability to execute a "shoot-look-shoot" attack. That rationale is an example of the "impractical war conduct scenarios" which one can set up and then show to be impossible if only some particular weapon is built, a panelist said. "That is not a valid reason to oppose ASAT treaties."

Finally, the argument that a U.S. ASAT weapon is needed to induce the Soviets to negotiate was also challenged. "It is not supported by historical experience," said a panelist. "In 1978 and '79, the negotiations [with the Soviets on anti-satellite weapons] were very active and were moving along nicely, and we didn't even have a paper program—much less a system." He pointed out that the Soviets "accepted it on faith" that the United States was quite capable, technologically and industrially, of putting together a system if it wanted to. "If both parties feel they can't negotiate except from a position of strength, the conclusion is there will be no negotiations."

LIMITATIONS OF ASAT ACCORDS ON BMD DEVELOPMENT

According to some panelists, the effects of an ASAT accord on the future development of ballistic missile defense are some of the most important anti-treaty arguments. "They involve important issues of judgement." While it was in effect, an ASAT accord would prevent development and deployment of space-based ballistic missile defense, said an accord supporter. However, any such treaty could have provision for periodic review. Treaties can be mutually eliminated or unilaterally abrogated; they contain "all kinds of possibilities for not constraining ourselves for the indefinite future." However, another panelist countered that treaties "tend to become sacrosanct." Any attempt to withdraw from an ASAT accord would become a "major political football" which might obscure strategic considerations.

URGENCY

One of the most important points raised by treaty supporters was that, if an agreement is to be reached at all, there is great value in reaching it sooner rather than later. A treaty may be much harder to negotiate, and be much less effective, if it is delayed. In particular, many treaty proponents thought it would be "extremely damaging" to complete tests of the U.S. air-launched ASAT because the Soviets will react to that development. If, following future American tests, the Soviets believe the U.S. system to operate reliably, they may not be willing to concede the United States' right to keep that system without demanding that they themselves be permitted to match or exceed that system's capabilities. "Quit while you're behind," urged a panelist, "or while you're nominally behind." In another panelist's words, "negotiating from strength is a sinusoidal function and you have to pick your timing right. . . . We should be negotiating now because we are behind by just the right amount."

In arguing for an agreement as soon as possible, one panelist noted that the negotiations need not take a long time. "You do not have to negotiate the ultimate ASAT agreement, and the best agreement to negotiate first is the broadest one." Another panelist countered that while an agreement need not take a long time, it probably will take a long time for reasons which are more political than technical. "If you don't want an agreement and you don't go to the table, it is likely to take a very long time" to negotiate and conclude a treaty.

Soviet Attitudes and Efforts

MILITARY EFFORTS

PAST DEVELOPMENT AND PRESENT STATUS

The Soviets have attached a great deal of significance to space activities. Their programs, controlled by the military, are a source of great national pride and have tremendous momentum. They have pursued all of the military support activities in space that the United States has undertaken, often for reasons not clear to American observers. The U.S.S.R. has also exploited options that the United States has forgone.

Development of the current Soviet co-orbital ASAT began in the 1960's for reasons which "really kind of remain something of a mystery" and quite possibly were not thought through in depth. It is not presently a very capable weapon. "I don't think that the orbital intercept system is of great military significance," said a panelist, echoing views which were widely shared at the workshop. "Indeed, it's hard to imagine exactly what threat it does pose." However, the Soviets have been taking the system very seriously. They have maintained it, tested it, and improved it over the years. They have not made major advances or introduced significant variants of the co-orbital ASAT, but instead have been systematically making incremental modifications. A panelist warned against drawing too many conclusions about the lack of major upgrades in the Soviet ASAT. The United States had maintained nuclear-armed ASAT interceptors on islands in the Pacific Ocean for 12 years without upgrades. We chose to develop an entirely new system—the air-launched direct homing interceptor—because that type of system had clear advantages. "There is no reason to suppose that the Russians might not have made a similar decision."

One must be careful in comparing the Soviet and the American space efforts. Many qualifications are required in order to determine true Soviet capabilities or level of effort. When comparing launch rates, for example, one must recognize that Soviet satellites are much shorter lived than American ones. Although the Soviets had 98 launches (military plus civilian) in 1983 compared to 22 for the United States, during that time the United States had about twice as many active satellites in orbit as the Soviets.

To some extent, the Soviet approach of having more but shorter-lived satellites reflects the Soviets' poorer technology; nevertheless, it does give them some significant strengths. They have replacement satellites and launchers and will be able to reconstitute space systems quickly in case of ASAT attack.

"The Soviets would fare better than we would in an environment in which satellites had an 'enemy-induced lifetime' of two weeks," said a panelist. "They would hardly notice it whereas it would hurt us a lot." However, he noted that if the United States deploys its ASAT, it will be able to destroy Soviet satellites within a few hours of launch. The Soviet ability to replace satellites every few weeks would not be very useful.

At present, the United States is seen by many observers as being more dependent on space systems than the Soviet Union. However, as the Soviets increase their use of space support systems, any asymmetry between Soviet and American reliance on space will lessen. Indeed, one panelist felt that the Soviets are now "fully as hooked on the use of those systems as we are," and that they are clearly using space systems in connection with their Afghan and other military ventures.

SPECULATION ON FUTURE DEVELOPMENTS

Future Soviet space activities are certain to increase and will appear provocative to many observers in the United States no matter what the "real" explanations may be. The Soviets will be undertaking "all sorts of operations at a level substantially higher than we're going

to be involved in." The Soviets are reportedly doing research and development into directed energy weapons, and at least one participant gave "considerable credence" to the notion that the Soviets might launch a space laser later in this decade. Such a device, rather than an incremental refinement of their co-orbital interceptor, would be required to deal with the American target set which has many satellites in very high orbits.

Another panelist cautioned that there has been, at times, considerable misrepresentation of the Soviet space program. "They may be working on lasers," he said, and "they certainly work on space." However, there has been "no significant, no credible report" of Soviet space-based lasers. "They could put a laser into space, just as we could," he continued, but it would be "militarily insignificant."

One participant questioned the relevance of speculating about Soviet motivations and developments, and of comparing the Soviet and American systems. "Useful as [that process] might be if better answers were available," he felt, it turns out "not to be a particularly illuminating way to go" in the present circumstances. "Maybe it's a diversion that really isn't very helpful at all."

DIPLOMATIC AND POLITICAL

SOVIET PERCEPTIONS

The Soviets currently say they see the U.S. strategic buildup as representing a desire to achieve and maintain a first-strike capability. Looking for means of countering this across-the-board buildup, the Soviets could see development of their ASAT weapons system as being an effective way to put very significant pressure on the United States with very little investment.

A panelist, attempting to view the American strategic rearmament program from the Soviets' "rather paranoid perspective," noted that the MX, the Trident D-5, and the Pershing II missiles are seen as being the "workhorses" of this presumed preemptive attack. Enduring command and control systems and ASAT weapons would fulfill vital support roles. If the United States were to pursue ballistic missile defense, it would be perceived, from this viewpoint, as enhancing a first strike posture by threatening to blunt Soviet retaliation.

American arms control overtures are also seen by the Soviets as supporting a U.S. first-strike capability, explained the panelist. Our proposals, which would have the effect of reducing Soviet force levels while not constraining the types of weapons programs we are undertaking, would just make it easier for us to undertake a first-strike attack.

POSSIBLE POLICY

The Soviets have stated their interest in resuming ASAT negotiations with the United States. They have been getting diplomatic credit for taking the initiative in promoting space arms control. The Soviets in 1981 and again in 1983 brought draft ASAT treaties before the United Nations. A major factor which seemed to have been a damper on U.S.-U.S.S.R. progress in the 1978 and 1979 ASAT negotiations had been the People's Republic of China's nonaccession to the Outer Space Treaty of 1967. After the OTA workshop had concluded, one of the participants informed OTA that the PRC had indeed acceded to the Outer Space Treaty as of December 1983--an event "of great importance."

Panelists noted that the Soviets have several incentives to negotiate an ASAT treaty with the United States. One is the argument "so frequently employed in American arms control negotiations: 'sure, we can make that proposal because, even though it might not be a good thing if it were accepted, we can count upon the Americans to not accept it simply because we propose it.' " Alternatively, and

contrary to their seeking to engage in an ASAT race to pressure the United States, the Soviets have an interest in limiting ASAT technology because that is an area where the United States might be able to excel. The Soviets are concerned that "we're going to push them into a technological race in areas where we have some advantage."

The Soviets have changed their public position since 1981. At that time, they would have permitted existing ASAT systems to remain under a treaty. Now, they claim that the U.S. weapon is too much more capable than their own to permit such an arrangement, and they will likely seek to ban it or else demand the right to respond with at least as capable a system of their own. A panelist noted that, should the Soviets seek to mirror the U.S. ASAT by deploying an air-launched equivalent, their BACKFIRE bomber would be a "splendid machine" for that purpose. It is large, fast, maneuverable, and can climb to high altitudes; BACKFIRES and their crews and logistical support exist in quantity.

The 1983 Soviet draft ASAT treaty modified or removed many of the features of the 1981 draft which had been considered objectionable from the American point of view. In particular, it did not include explicit objection to the U.S. space shuttle. The Soviets do not find the space shuttle to be an object of "fear and loathing," said a panelist. He dismissed the idea that, using the space shuttle, the United States might "swallow one of their satellites and bring it back to Los Angeles or somewhere and dissect it." "I would strongly suggest that we not try that," he continued. "The first time we try it, we will have three shuttles instead of four."

However, Soviet attitudes concerning the shuttle might very well be modified by use of the shuttle for anti-satellite experiments or tests. *Aviation Week and Space Technology* articles cited at the workshop report that anti-satellite related activity is scheduled for future shuttle missions. Although the Soviets have indicated an understanding of the importance placed by the United States on protecting shuttle activities, including those involving military support, it was felt at the workshop that their tolerance would not extend to active ASAT experiments. One panelist felt that, in reaction to U.S. ASAT activity (shuttle-related or otherwise), the Soviets may go so far as to challenge such long-established precepts as right of overflight of Soviet territory by military-support space systems.

Other panelists made the observation that it would be "very surprising" if the Soviets, in concluding an ASAT treaty, would be prepared to give up the capability to attack elements of a strategic weapons system based in space. This would apply in particular to space-based elements of a strategic defensive system.

A panelist noted that by vigorously pursuing space activities and at the same time seeking space arms control negotiations with the United States, the Soviets could be indicating that they would like to draw up some rules of behavior which would permit them to expand their space activities in a way that is "reasonably safe and reasonably in concordance with what we want to do." Lack of significant progress on their co-orbital ASAT should not be taken as indicative of a desire for arms control. "I don't think that it's useful or that it's likely to succeed to rest the case for arms control on evidences of Soviet restraint. . . . They will restrain themselves when they see a political purpose to it, and the arms control agreement or other agreements provide the political purpose for it." Without disagreeing, another panelist cautioned against attributing to the Soviets the same policy or operational doctrine concerning ASATs as the United States holds. "We have a notion of what we think ASAT development or ASAT arms control would do within the context of American security policy . . . [but] it is not obvious to me that they are going to make those judgments in the same way we do."

U.S. Attitudes and Efforts

BACKGROUND

DEPENDENCE ON SPACE SYSTEMS

The United States has placed high importance on the utilization of space for military support operations. It has developed advanced space technology which is deployed in valuable, sophisticated, and long-lived satellites. Space systems are particularly attractive to the United States in view of its policy of being able to project power worldwide. The high capability and high cost of American satellites, however, tend to make them attractive targets for ASAT attack. We have not expended much effort in the past making these assets redundant or survivable, increasing the motivation for the Soviets to develop an ASAT.

At the same time, the U.S. has recognized the vulnerability of space assets and has not relied on them as extensively as it otherwise might have. For example, the space-based Global Positioning System, when fully operational, will permit increased accuracy of U.S. strategic missiles, but guidance of U.S. ICBMs and SLBMs will not rely solely upon that system. Space systems play a very important role in military support which should not be underestimated, but critical, indispensable systems are designed with minimum dependence on satellites. If space links are involved, they are part of a redundant set of alternatives. As a result, there has not been a strong incentive to develop ASAT weapons.

Possibly more significant than our partial dependence on satellites, thought some panelists, is our moving towards total dependence on the space shuttle as a launch vehicle. "If the Soviets have an interest in impeding or disabling all or some parts of our space program, the way to go to the jugular is to go to the shuttle," remarked a panelist. "The Air Force's claims that there is need for retention of conventional launch capability are absolutely correct."

ANTI-SATELLITE SYSTEMS AND NEGOTIATIONS

In the 1960's, the United States maintained an operational system of nuclear-armed ASAT interceptors at Johnston Island and Kwajalein atoll in the Pacific Ocean. These were decommissioned by 1975 for several reasons, including: 1) the threat of orbiting nuclear weapons, which the ASATs were intended to counter, never materialized; 2) nuclear ASAT detonations in space would damage friendly satellites and terrestrial systems by electromagnetic pulse (EMP) generation; and 3) the existence of the nuclear-armed ASAT system formed a disincentive to spending additional money on a more sophisticated and more usable ASAT weapon. In 1978 and 1979, the United States held three rounds of bilateral negotiations with the U.S.S.R. concerning ASAT weapons. The talks were never resumed following the Soviet invasion of Afghanistan.

PRESENT POLICY

Although administration representatives were invited to participate in the workshop, none did so. As a result, the panelists attempted to represent administration positions from the perspective of outside, interested, and knowledgeable observers, and at times cited administration testimony before the Senate Foreign Relations Committee.

ASAT ARMS CONTROL

Present Reagan Administration policy is to complete development and deployment of the F-15-launched, direct-ascent ASAT interceptor and to defer ASAT negotiations which have been sought by the Soviet Union. Three reasons have been given to Congress for building a U.S. ASAT weapon: 1) The existence of the Soviet ASAT requires that the United States develop an equivalent capability in order to deter Soviet ASAT attack, 2) the United States requires an ASAT in order to compel the Soviet Union to enter ASAT weapon negotiations in good faith, and 3) the United States requires the capability to deny the Soviets use of space assets which support attacks against U.S. forces.

Inadequate verification has been the primary stated reason for the United States not responding positively to Soviet requests to resume ASAT negotiations. Difficulty in verifying the destruction or ensuring the absence of dedicated ASAT systems, and the inevitable existence of potential residual ASAT capability (Galosh ABM interceptors, Soyuz rendezvous procedures, etc.) have been cited as being impediments to treaty verification. Potential residual or covert Soviet ASAT capability has been felt to preclude an effective ASAT treaty. Pursuit of the Strategic Defense Initiative, which would likely be impeded by effective ASAT arms control, may have been a factor in the opposition to ASAT negotiations but had not been brought up in testimony before the Senate Committee on Foreign Relations as of early 1984 (the most recent testimony offered before that Committee had been in May 1983).

ASAT arms control was not seen by the panelists as being high on the incoming Reagan administration's list of priorities. Its most important military objective was to build up strategic forces, and ensuring the survivability of military support satellites was made a very high priority. Strategic Arms Reduction Talks and Intermediate Nuclear Forces negotiations may have been a priority, but ASAT negotiations certainly were not. The possibility of future ASAT talks had not been foreclosed, but it was felt that they could be considered at some future time if they were seen to be in the national interest. For the time being, the Air Force was to continue development of the air-launched ASAT weapon.

A workshop participant noted that it seemed as if there had been no net assessment, at least in the first three years of this administration, of the overall advantages and disadvantages of an ASAT treaty. ASAT was not a priority issue, so there was no motivation for overcoming bureaucratic impediments against "getting the focused attention either of persons who don't wish to agree or of the person who can tell them to." The lack of such a comprehensive policy, if it indeed is missing, is likely due to the lack of ongoing ASAT negotiations. During the 1978-79 ASAT negotiations, there was incentive to formulate an administration-wide policy. "Negotiating with the Soviets was really driving the whole process" at that time, observed a panelist.

ARMS CONTROL IN GENERAL

The Reagan administration reevaluated previous administrations' attitudes towards arms control. It was felt by members of the incoming administration that many previous arms control agreements had not been in the best interests of the United States. Negotiations which had led to treaties had had the effect of codifying and preserving the status quo. Since the new administration felt that the United States was in an unsatisfactory military balance with respect to the Soviet Union, taking into account rates of buildup as well as levels of deployed forces, this imbalance would have to be redressed before there was much hope of successful arms control. "The burden of proof," explained a panelist attempting to interpret administration attitudes, "would be on those who argued that an arms control negotiation about anything was more likely to succeed if begun in 1981 than if begun in 1982 or 1983 or 1984 or 1986 or 1987."

Panelists also perceived an assumption within the administration that it would be a mistake to modify military programs to meet arms control objectives — either to make arms control successful or to rely upon successful conclusion of an agreement. "If a program makes sense in the absence of arms control," voiced a panelist attempting to represent this attitude, "then that program makes sense, and one should not think about the alternatives of either 'go ahead with this program' or 'go ahead with an arms control treaty'."

Administration policies seemed to some panelists to be consistent with an attitude, held implicitly by administration policymakers, that the U.S./U.S.S.R. relationship will be one of military competition for the indefinite future. "It is beyond the ability of policy makers to opt out of that competition," as restated by a panelist. However, "the policymakers may have some choices about where that competition takes place." It would therefore make sense for the United States to steer the military competition into an arena where the United States might excel—developing and deploying sophisticated technology, such as space technology—and away from competitions which just involve spending money, such as putting tanks into Central Europe. Along these lines, there are those who argue that space is where the United States can "outflank" the Soviets and sustain some kind of superiority, and that consequently an ASAT treaty might be one of the less attractive arms control possibilities.

ASAT, BMD, and the 1972 ABM Treaty

ASAT systems and anti-ballistic missile systems are closely related, as are ASAT and ABM arms control. The development of ASATs can affect the continued viability of the existing ABM arms control regime; conversely, development of strategic defensive systems can affect possibilities for ASAT arms control. This section reviews the 1972 ABM treaty ("I have a rule . . . never to be flabbergasted at the same thing more than three times," explained a panelist, "but I am always somewhat surprised at how people forget what it is that the treaty says and what it does not say"). This section also discusses some of the relationships between ASAT and ABM, regarding both weapons systems and arms control measures.

REVIEW OF 1972 ABM TREATY

PURPOSE

The Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems, which entered into force on October 3, 1972, states its overall purpose in Article I:

> 1) Each party undertakes to limit anti-ballistic missile (ABM) systems and to adopt other measures in accordance with the provisions of this Treaty.
>
> 2) Each party undertakes not to deploy ABM systems for a defense of the territory of its country and not to provide a base for such a defense, and not to deploy ABM systems for defense of an individual region except as provided for in Article III of this Treaty.

This explicit declaration of purpose is an important aspect of the treaty. As time, technology, and circumstances change, it is possible to refer again to the declared purpose in order to develop specific new understandings which are required to modernize the treaty.

DEFINITIONS

An anti-ballistic missile system is defined, for the purposes of the treaty, as "a system to counter strategic ballistic missiles or their elements in flight trajectory." This phrase is followed by the words "currently consisting of" and then a list of three items: ABM interceptor missiles, ABM launchers, and ABM radars. The treaty is not restricted to those systems. It says what the current systems are, but it is intended to cover all ABM systems.

Note that the definition refers to strategic weapons. Systems to counter tactical missiles are not covered at all—"a loophole that we designed carefully, and which they are pushing through," according to a panelist (see app. B). Note also that the treaty defines an ABM as a system to counter strategic weapons. It does not say "system designed to counter," as the Soviets would have liked, nor does it read "system capable of countering," which was the United States' preferred wording. The United States was concerned that, by upgrading surface-to-air missiles (SAMs), the U.S.S.R. would be able to deploy a considerable ABM capability. The Soviet Union, on the other hand, was concerned that it would be forced to classify some 10,000 SAMs as ABM interceptors. The analogy of upgrading ASAT weapons to give them ABM capability is similarly relevant and similarly covered by the treaty.

This definition is essentially a capability test. All systems which are ABM-capable, whether or not they were designed for that purpose, are either considered ABM systems under the treaty or else are in violation of Article VI(a), which prohibits giving ABM capability to non-ABM systems. This article was "really aimed at SAM systems," explained a panelist, "but the same thing applies to ASAT systems." If an ASAT weapon is given the ability to counter strategic ballistic missiles,

then "it's a violation or else it's got to count as an ABM system, one way or the other."

MAJOR PROVISIONS

The ABM treaty prohibits all ABM deployments which are not explicitly permitted. Article III bans all deployments other than two sites (amended by a 1974 protocol to one) on each side, each having restricted numbers of interceptors, launchers, and radars. These prohibitions, interpreted a panelist, are clear: "Can you deploy lasers? No. Can you deploy particle beams? No. Can you deploy squizzle dumps or freeble dobbles? No."

Article IV permits testing, at designated test sites, of certain systems not deployable under Article III. However, systems permitted at test sites or deployments are severely constrained by Article V, in which "each party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based." Only fixed, land-based systems can be tested, and only specified fixed, land-based systems can be deployed. "Development," as referred to in this provision, was defined in a statement to Congress by the chief U.S. negotiator of the ABM treaty: "It is understood by both sides that the prohibition on development applies to activities involved after a component moves from the laboratory development testing stage to the field testing stage, wherever performed." Interpreted by a workshop panelist, "if I see one outside the laboratory—a prototype, a bread-board model—if I see one, it's a violation. I don't have to see it tested." The second part of Article V prohibits a launcher from being able to fire more than one interceptor or be reloaded rapidly.

Upgrades are prohibited in Article VI(a), as discussed above. No non-ABM systems shall be given ABM capability or be tested in an ABM mode. The second part (b) of Article VI restricts ABM battle management radars by requiring early warning radars to be on the periphery of the country and oriented outwards. Agreed Statement F, approved by U.S. and U.S.S.R. delegation heads at the same time that the treaty was signed, excludes radars used "for the purposes of tracking objects in outer space or for use as national technical means of verification" from the location and orientation restrictions in Article VI(b).

Article XII prohibits interference with verification of the treaty, both by banning interference with the national technical means used for verification and by prohibiting "deliberate concealment measures" which would impede verification by national technical means. Article XIII establishes the Standing Consultative Commission to handle questions relating to treaty compliance, to consider possible amendments, and to consider proposals for further limiting strategic arms.

Agreed Statement D of the ABM treaty discusses components based on "other physical principles" and capable of substituting for interceptors, launchers, or radars. Capability, again, is crucial. If a new device can substitute for a launcher, interceptor, or radar, its deployment is prohibited. If it is instead only an adjunct or supplement, it would be permitted. This article specifies that "specific limitations" on such new systems and their components would be "subject to discussion" in the Standing Consultative Commission, and that such discussion might lead to amendment of the treaty. Only if the treaty were amended to permit these new components would their deployment be allowed; otherwise, they are prohibited.

CONNECTIONS BETWEEN ASAT, BMD, AND THE ABM TREATY

As mentioned above, developing an ASAT system which had BMD capability, or upgrading one to give it BMD capability, would be a violation of the ABM treaty. The test of violation is capability—can the ASAT destroy missiles? There is an absolute prohibition on anything not fixed on land at an ABM site or a designated test site which is able to destroy "strategic ballistic missiles or their elements in flight trajectory."

National technical means of verification are protected from interference in Article XII. Reconnaissance satellites are not explicitly mentioned in the treaty text, but they are listed as an example of national technical means in the transmittal letter from the Secretary of State to the President which accompanied the treaty and were also mentioned in the transmittal letter to Congress. ASAT attacks against reconnaissance satellites used to monitor compliance with the ABM treaty are, therefore, banned by that treaty.

Another relevant connection between ASAT systems and the ABM treaty involves the radars required for ASAT battle management (in the absence of an ASAT treaty) or ASAT treaty verification (if such a treaty is concluded). These space-track radars will physically be very hard to distinguish from early-warning radars and ABM battle management radars which are covered by the ABM treaty, and any ASAT treaty may need specifically to address space-track radars to ensure that the prohibitions against ABM battle management radars are not circumvented. However, according to a panelist, the signal emitted by a radar "would be quite different if it were fundamentally a space track system than if it were an ABM," making somewhat easier the task of distinguishing between the two (see app. B).

TECHNOLOGIES

There is great overlap between BMD and ASAT technologies. In general, even a poor or prototype anti-ballistic missile could be an excellent ASAT. Looking at BMD systems designed to attack a ballistic missile at different stages in its flight trajectory, we have three categories of BMD systems:

1. **Boost-phase BMD.**—BMD systems designed to attack missiles as they are climbing out of the atmosphere under powered flight have great ASAT potential. Therefore, any treaty effectively limiting systems having ASAT capability would almost certainly have to restrict boost-phase BMD. Of course, the ABM treaty already in effect prohibits boost-phase BMD: in order to respond quickly enough to attack missiles in their boost phase, a boost-phase BMD system will either require space-basing of weapons components or else it will need to launch "pop-up" components immediately upon detection of missile launch by space-based sensors. It may well also require directed-energy weapons which produce beams propagating at or near the speed of light. "Both of those are prohibited by the ABM treaty," reminded a panelist. "It's not as if there's some little, subtle question as to whether a space-based BMD system would be permitted or not. It's not. You can't develop it, you can't test it, you can't deploy it, and it's caught in about eight different places in the treaty. It is not close."
2. **Midcourse BMD.**—The trajectory of a missile reentry vehicle while outside the atmosphere is similar to a satellite orbit: the peak altitude is on the order of 1,000 km and the velocity is slightly suborbi-

tal. There is therefore great overlap between midcourse BMD systems and ASAT systems. The Soviet Galosh ABM system was not designed as an ASAT but does have ASAT capability for satellites in orbits similar to ICBM trajectories; the U.S. miniature homing vehicle ASAT weapon evolved from a design originally intended for midcourse BMD. Since the ABM Treaty strictly limits locations of permitted ABM systems, there are significant constraints, in terms of number and location, on ABM systems which could be used as ASATs. Including the interceptors at test ranges, each side would have only about 115 interceptors and they would be located between 45 and 60 degrees latitude. ABM systems permitted under the treaty are therefore "important for some kinds of satellites in certain kinds of orbits, in certain places," but they are "probably not a very significant threat" to satellites in general. In addition to the constraints in the ABM treaty, midcourse BMD (like boost-phase BMD) would probably be inhibited by an effective ASAT treaty.

3. **Terminal BMD.**—BMD systems which attack missile warheads after the warheads have re-entered the Earth's atmosphere have the least overlap with ASAT technology. They are also not very useful systems for defending large areas, as opposed to selected hardened targets. While research into terminal BMD systems is proposed as part of the Reagan administration's Strategic Defense Initiative, they are not the systems primarily responsible for the renewed interest in ballistic missile defense pursuant to the President's March 23, 1983 "Star Wars" speech.

ROLES

Since ASAT and BMD technologies are so closely related, the outcome of any ASAT limitation or testing ban will almost certainly impede midcourse and boost-phase BMD development. Conversely, technology development ostensibly for an advanced ASAT system might provide a loophole for undertaking BMD research which would be in violation of the ABM treaty.

At the same time, the development of high-quality ASATs which will probably occur in the absence of an ASAT agreement would put the space-based elements of any BMD system (sensors if not weapons) at risk. Unconstrained ASATs would threaten sensors even for ABM systems which are within the scope of the present ABM treaty.

PERCEPTIONS

As noted above, aggressive ASAT development will aid development of advanced BMD systems since technologies investigated for ASAT may be useful in either role. ASAT development may therefore be perceived as supporting a BMD program. To the extent that development of BMD is seen as being threatening, ASAT development may likewise be perceived to be a threatening act.

In a political context, a participant suggested that some of the hostile implications of pursuing BMD research might be ameliorated by simultaneously pursuing some sort of space behavior or "rules of the road" agreement.

DRAFT ASAT TREATIES

The 1983 Soviet draft ASAT treaty includes a subtlety of language which may or may not have been intended. The phrase "space object" is a negotiator's "term-of-art" originating with the Outer Space Treaty negotiations. It stands for anything in space **except for** ballistic missile reentry vehicles, which were purposely and carefully exempted from the jurisdiction of that treaty. Although the Soviet draft mentions space objects in the introduction, an operative article prohibits testing and deploying "space-based weapons for the destruction of objects on the Earth, in the atmosphere, or in outer space" (emphasis added). It does not say "space objects," implying that attacks on reentry vehicles would not be excluded from

the ban. One participant, noting that the "Soviets are not dummies when it comes to treaty language," thought that quite possibly they intended to use language that was "opaque as to their views" which would "invite us to reveal our views of some of these substantive matters through the route of fiddling around with these language details."

The draft ASAT treaty proposed by the Union of Concerned Scientists, on the other hand, prohibits attacks on "space objects" and therefore does not address the problem of attacks on reentry vehicles. That exemption was made because the ABM problem had been explicitly addressed in the 1972 ABM treaty. "There is a tendency in drafting treaties to make the treaty stand by itself," commented a panelist. "That should be resisted. Every treaty exists in the milieu of other agreements."

At least one participant disputed the value of preparing drafts outside of an ongoing process of negotiation: "I do not like the idea of people putting out draft treaties on ASAT matters." They are invariably "incomplete" since the text alone does not include any of the history that accompanies a true negotiation process and since the authors are not necessarily official representatives of their governments. The "prejudicial effects" of extant drafts "could probably be dismissed in a couple of weeks," but that time could be put to better use should negotiations be resumed.

TREATY WORDING

The language of the ABM treaty was left "fuzzy" in places, and definitions were not made overly precise, in order to leave a "no-man's-land" surrounding prohibited areas. The hope was that debate would ensue as to whether the "no-man's-land" had been entered before there were any questions of treaty violation. This "noble experiment," however, did not provide the desired results. "It turns out the Soviets are creatively legalistic," interpreted one panelist. "They don't worry about the fuzzy areas. In their view, action in a fuzzy area is permitted because it's not prohibited."

However, the suggestion that the Soviets do not uphold the spirit of a treaty was debated by another panelist. "I don't like to talk about the 'spirit of agreement' because there ain't no such thing." However, this panelist noted that there is significant value in having an operative article in a treaty which states the treaty's general purposes. When circumstances change, forcing development of new understandings in order to maintain the treaty, one can look back on that declaration of intent to make an easy transition. "Here is the agreed purpose that's built into the treaty. Here are the new circumstances that bear on that purpose, and here are the new specific understandings that are needed to modernize" the treaty.

Verification Issues

CAVEATS

Verification issues are inherently difficult to discuss in an open meeting. However, a panelist pointed out that verification is much more than a detailed catalog of technical intelligence capabilities. Another panelist agreed, noting that the intelligence agencies say that their job is not verification, but monitoring. They make that distinction very clearly, he explained: "verification" is a political, legal, diplomatic, and military process, of which "monitoring" is only a part.

Workshop panelists started the session devoted to verification by making two observations. First, verification is concerned with determining whether or not specified treaty provisions are being complied with and is therefore inherently dependent on the wording of those provisions. Second, any discussion of verification ought to include consideration of the overall military or security purposes which the treaty is to serve. The level and confidence with which compliance with a provision need be verified must depend on the significance and implications of violating that provision.

GOALS

Therefore, any discussion of verification technology and procedure must implicitly or explicitly be preceded by discussion of philosophy—what is it that the treaty is to accomplish? Five not necessarily mutually exclusive goals of a space arms control or space behavior agreement were identified at the workshop:

1. to reduce the vulnerability of existing space assets to dedicated or residual ASAT threats by constraining those threats;
2. to prevent future development of a high-confidence, high-quality ASAT by the opposing party;
3. to relax tensions between the superpowers by establishing a regime of acceptable behavior in space;
4. to obtain political or diplomatic goodwill; and
5. to avert or constrain an arms race in space.

Some aspects of a treaty may be much more relevant for achieving the principal purposes of the agreement than others, and therefore it may be more important to verify some portions of an agreement than others.

LEVELS OF VERIFIABILITY

Some provisions in a treaty may serve to ban activities which are not very threatening in themselves but are prohibited in order to ensure that other, more threatening activities are not undertaken. In these cases, the activities which are of less concern might not need to be detected with as high a level of confidence as long as there were higher confidence that the more threatening activities were not taking place. As an example, consider a ban against testing ASAT interceptors at geosynchronous orbit, which would be a more threatening act than testing them in low Earth orbit. It might be easier to ban these high altitude tests if tests in low earth orbit were also prohibited. Even if some low-altitude tests were conducted covertly by masking them as legitimate rendezvous operations, the

low-altitude ban might prevent overt, explicit low-altitude ASAT tests which might be more easily adapted to higher orbits than a covert capability would be.

Limitations which might not be highly verifiable, taken alone, might nevertheless be useful in an agreement as long as one understands the limited contributions such bans might make to security. Subversion of even a leaky ban would require a totally covert program, which would certainly be more difficult than an overt one and which may or may not be possible. Furthermore, technical encroachment of a treaty proscription by a single component is not the same as development of a militarily significant system. "Soyuz can ram satellites," admitted a participant, "but you have to have one hell of a lot of Soyuzes floating around to make a terribly militarily effective ASAT system."

The problem of levels of verification has arisen in previous arms control issues. "In the late 1970's, there was some agreement among a large fraction of the community," said a panelist, "that although cruise missile verification could not be absolute, verification could be good enough considering that they did not pose a first strike threat." Another panelist noted that we do not necessarily have to respond to weaknesses in our verification capabilities by either contorting arms provisions to avoid the weaknesses or by avoiding arms control altogether. There are defensive means other than arms control, such as hardening and survivability measures or changes in operational procedures, which can offset the military advantage that might accrue to a party attempting to cheat on an agreement.

FACTORS IN VERIFICATION OF ASAT ARMS CONTROL

COMPLICATIONS

Discussion of ASAT arms control brought forth several factors which tend to complicate the verification of compliance with such an agreement, and several other factors which ease that task. One of the complications is the enormous volume of space where illicit activities might be conducted. Verification of compliance with a SALT or START arms control agreement involves inspection of number of areas within the Soviet Union or its immediate airspace. This area, although vast, is relatively well determined and is amenable to close inspection by space-based photographic reconnaissance satellites. The region where space activities might be conducted starts at altitudes of about 100 km and can range well past geosynchronous orbit at 36,000 km. Also increasing the difficulty of verifying compliance with an ASAT treaty is the large number and growing variety of Soviet space launches. Soviet launches have increased at a rate of about 2 percent per year, averaged over the last 15 years. Although this launch rate may very well decrease in the future as the Soviets develop longer lived satellites, each additional type of satellite requires a body of experience in order to classify its function and permit discrimination between unusual activity and routine behavior.

Third, the functional characteristics distinguishing ASAT weapons or space mines from other satellites may not be readily observable. All national technical means have imperfect discrimination, and the physical differences between permitted and prohibited satellites may be small. As panelists had previously pointed out, much Soviet space activity is not likely to be completely understood by the United States no matter what the "true" Soviet intent might be.

A fourth complication is the inevitable presence of some residual ASAT capability in systems which may be undesirable or infeasible to ban. ICBMs, SLBMs, ABM interceptors, maneuvering spacecraft, and possibly air-

based or ground-based lasers may fall into this category. These systems may pose problems in determining whether they are being operated in an ASAT mode; normal operation (of rendezvous between spacecraft, for example) may be difficult to distinguish from certain types of ASAT activities. This question of residual ASAT capability is one of the most crucial factors in the debate concerning the desirability of an ASAT accord, and just how much ASAT activity could go undetected is a critical question. As the number of systems possibly having some ASAT capability proliferates, the monitoring task of determining how these systems are being used will become even more difficult.

A fifth, somewhat ironic, point made during this discussion was that at present, the principal motivation for the United States to develop the sort of space monitoring capability which would be useful in verifying an ASAT accord is to provide targeting information for the U.S. ASAT weapon. Panelists did note, however, that it is likely that any monitoring capability needed to verify a treaty would be desirable in any case. Intelligence collection requirements would persist even in, or especially in, the absence of a treaty. However, the lack of an ASAT weapon system might reduce the bureaucratic enthusiasm or political backing for an extensive space monitoring system.

SIMPLIFICATIONS

Mitigating these complications are several offsetting factors which assist our capability for monitoring space arms control. First, although space is large, it is transparent and accessible to monitoring, and weaknesses in ground-based monitoring systems can be mitigated by putting those systems into space. Soviet satellites will be observable by U.S. national technical means. Confusion as to the true nature of a Soviet spacecraft may be mitigated by an agreement which will serve to reduce ambiguity of space operations. Furthermore, all ASAT-related activities start on the ground. Relevant ground sites, including launch facilities, can be observed by an extensive array of U.S. monitoring facilities; all launches of significant size from Soviet territory can now be detected. After all, although the Soviets have never publicly announced their existing ASAT tests, these tests have been detected and analyzed by the United States.

Second, if the Soviet Union attempts to conduct covert ASAT testing or development, it will need to monitor its own activity if it intends to obtain any data concerning how well its system performs. The Soviet requirement to recover data from or observe its activity in some way may also provide the United States with an opportunity to detect or intercept the transmission. The Soviet need to hide covert testing from the United States may narrow down the regions where the United States need concentrate its own verification effort.

Finally, the claim has been made that unattainably stringent levels of verification are needed for an ASAT treaty because U.S. targets are few and valuable and therefore vulnerable to even a small amount of cheating. This reasoning was thought by many participants to be not so much an argument against an ASAT treaty as it was a compelling reason for the United States to increase the survivability of its space systems. Rather than precluding arms control, the situation of having few but valuable satellites calls for having alternatives to them. "If the United States is truly and genuinely that dependent upon a few satellites, I'd just like to know what the hell DOD plans on doing about it, because in the absence of any ASAT arms control, the problems are only worse."

VERIFICATION PARTICULARS

The verification discussion was explicitly not intended to be an exhaustive analysis. Security considerations, in particular, prevented many highly relevant points from being studied in detail. However, like the other workshop sessions, the session on verification did serve to foster discussion on a range of topics.

One participant pointed out that ASAT treaties would ban, first of all, the act of destroying satellites, and that this aspect of any ASAT treaty is readily verifiable. Less clear was how detectable the capability to destroy a satellite or its ability to function would be.

Satellite failure can easily be detected. Although there was concern that the Soviets might be able to develop a system which could cause one or two U.S. satellites to fail in a manner mimicking an equipment malfunction, panelists noted that satellites presently have a lot of on-board "state-of-health" monitoring. These sensors can be augmented to determine whether a failure is due to an internal flaw or whether it has been externally induced. Satellites can have sensors to measure incident laser light, rises in temperature, or sudden accelerations, for example. A satellite's location or behavior might also indicate a cause for its failure, either hostile or benign. Therefore, the Soviets would not have high confidence that covert interference would remain undetected.

Central to the ASAT arms control debate is the level of residual or covert ASAT capability which could remain, or be developed covertly, after a treaty had been ratified. A panelist noted that capabilities associated with known ASAT launch sites and research and development facilities would be detectable. The detectability of other possible residual or covert activity was more controversial. One possible "worst-case" evaluation of ASAT capability which might be covertly developed or maintained under a test ban was attempted at the workshop. Again, no detailed assessment of the likelihood of these developments, or of the particular means the United States could employ to search for them, was undertaken. There was, however, a general feeling that nothing arose in that evaluation which would clearly permit covert development of a high-confidence, high-quality ASAT weapon under such a test ban, although some panelists did express strong reservations about the detectability of nuclear space mines and ground or air-based lasers. ASAT capability is categorized below by technology.

DIRECT INTERCEPTION

1) **Fully capable, dedicated, tested systems.**—Neither the United States nor the U.S.S.R. now has such a system. Developing one would require an extensive testing program. If such a proposed system were to be similar to the existing Soviet ASAT, its launches would be visible; orbiting vehicles would be noticed, especially maneuvering ones. If such a direct intercept system were to be similar to the U.S. miniature homing vehicle, its ascent could be seen, its telemetry could be detected, and its target could be seen. Suspicious rendezvous operations in space could be inquired about. Tests against points in space would eliminate any observation of the target, but there would be concomitant loss of confidence in the results of the test.

2) **Existing Soviet ASAT.**—Tests of the existing Soviet ASAT can be monitored. We possibly would not be assured that all ASAT interceptors had been destroyed pursuant to a ban, but we could with high reliability know if one had been tested. There will certainly not be high confidence that an ASAT interceptor would work reliably mated to a booster it has never been tested with. Even with no major design change, the confidence in and significance of any untested system is bound to degrade with time.

3) **Residual "baling-wire" direct intercept ASAT.**—One can never rule out the existence of some covert, improvised ASAT capability of this sort, but one can deny high confidence in such a system by preventing tests.

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4) Nuclear-armed ICBM or ABM missiles used as ASATs.—Testing nuclear warheads in space is risky, in terms of collateral damage to friendly systems; prohibited, under the limited test ban treaty; and easily detectable. (Testing warheads underground could be done with high confidence.) Nuclear ASAT capability cannot reasonably be prohibited since ICBMs and possibly ABMs will exist with or without an ASAT treaty. Workshop panelists felt that such systems did not present a significant ASAT threat except during nuclear war, in which case damage to satellites would be likely whether or not it had been intended. "The Soviets are bad, but they're not lunatics," said one panelist, "and I can just see no credibility whatsoever in the notion that they'd fling a nuclear weapon up into the heavens and crack it off. It would cost them a lot."

5) Non-nuclear ICBM or ABM used as ASATs.—With appropriate radar support, it is possible that the Soviet Galosh ABM could perform ASAT attacks with a non-nuclear charge. Galosh deployment and testing are permitted under the ABM treaty, but the location of the launchers and the consequent range of orbits at risk are limited by the ABM treaty and protocol. Testing of an ICBM or ABM in an ASAT profile would be prohibited under an ASAT test ban, would be differentiable from ABM tests, and would likely be detected.

"SPACE MINES"

In general, any satellite very close to another country's satellite is a priori suspicious. Any mine or weapon which would be effective from further away is a complex system which requires maneuvering or pointing and would therefore require testing. These tests would be detectable. Concerning close approach, however, panelists noted that under the regime presently existing on the high seas, opposing forces do have the right to make close approaches. Banning close approaches in space would require codification of principles not incorporated in present law. Such an agreement would be highly verifiable, and could be made even more so by putting potential target satellites in orbits "out in the middle of nowhere" where there would be no innocent reason for other satellites to be anywhere nearby at all.

1) Non-nuclear space mines.—These would have to get very close (on the order of 1 km) to their targets. There would be no innocent reason to have a satellite that close to another country's satellite, and such approaches could be easily detected.

2) Nuclear space mines.—The Outer Space Treaty of 1967 prohibits orbiting of "nuclear weapons, or any other kinds of weapons of mass destruction." Nuclear space mines are therefore presently prohibited. There are also significant inhibitions (collateral damage, breaking the nuclear threshold) against their use for ASAT (see "Nuclear-armed ICBM or ABM missiles" section above). At present, nuclear space mines can easily be built, tested underground, and deployed. However, actual emplacement of mines within a nuclear kill radius (100 to 200 km) of their targets, or of mines able to be maneuvered within that range, would likely be identified from tracking data. Inspector satellites that could detect nuclear weapons in space satellites were briefly discussed. However, they may not be technically feasible, and negotiating an agreement regulating their use might pose problems (see "Cooperative Verification Measures" section below).

3) Projectile-emitting.—Satellites carrying interceptors which could travel 100 kilometers or so to their targets could similarly be identified from tracking data; furthermore, projectile-emitting satellites would likely require extensive testing of their target acquisition and homing systems, and these tests would likely be detected.

DIRECTED ENERGY WEAPONS

1) Space-based directed energy.—Space-based directed energy weapons might best be considered space mines with kill radii of hundreds to thousands of kilometers since they are ef-

fectively instantaneously acting. Space-based, non-nuclear-pumped lasers would be quite large and may emit hydrogen fluoride or other gases. Their operation and testing would be observable. Nuclear-pumped directed energy weapons, like non-directed nuclear weapons, could not be tested covertly in space, and placing them into orbit is contrary to existing treaties. On-board nuclear weapons might be searched for (see discussion of inspection in "Cooperative Verification Measures" below).

2) **Air-based, ground-based, or pop-up directed energy.**—All such systems would require testing. Possible targets could in principle be monitored to see if they are being illuminated by strong lasers, are giving off gases, are being unexpectedly accelerated, or are emitting unusual signals. Air and ground-based systems may be detectable by national technical means; furthermore, they are increasingly less effective as the target altitude increases, since intensity drops off as the square of the distance between the weapon and the target. It is far easier to blind an optical sensor than to damage a satellite, requiring probably one millionth of the energy. Lasers capable of blinding sensors are easily available, so the capability of blinding sensors cannot be banned. However, the act of blinding a satellite would be readily detected: after all, "imaging satellites are only so particularly vulnerable when they are looking at you."

SPOOFING, JAMMING, OR OTHERWISE INTERFERING WITH THE OPERATION OF SYSTEMS USING SATELLITES

These categories would likely not be covered under an ASAT testing ban, since ensuring the absence of such capability would not be verifiable. Furthermore, the United States is not likely to negotiate away the capability to interfere with hostile satellites in these ways: "We would like to do that, we're very good at doing that, and we intend to do that in case of conflict."

COOPERATIVE VERIFICATION MEASURES

Some of the verification techniques discussed at the workshop would require, or would at least greatly benefit from, cooperative verification procedures between the United States and the U.S.S.R. Just one example would be verifying the absence of orbiting nuclear weapons, although such measures might be useful in many other cases as well.

If the capability for detecting nuclear weapons in orbit were felt to be required (note that the 1967 Outer Space Treaty forbidding them was ratified, and remains in force, in the absence of such explicit procedures), some sort of co-operative program would need to be established. One method mentioned at the workshop might involve a form of "on-orbit" inspection. In that example, all satellites would be required to withstand some level of neutron irradiation. On demand, suspect satellites would be subject to such irradiation from an orbiting inspector satellite. Emission of delayed neutrons from the target would reveal the presence of fissionable material. Alternatively, non-intrusive examination for fissionable material might be done on the launch pad.

There are several difficulties with inspection in orbit. In the case mentioned above, for example, it might be possible to conceal a nuclear warhead by shielding it appropriately. A more general problem with any "on-orbit" inspection is that the inspector satellite, requiring the capability to acquire, track, and rendezvous with a target satellite, would have and would regularly test all the attributes of an ASAT interceptor except for detonation of a warhead. Another problem with actively probing inspections in particular, noted a panelist, is that "if it's carrying an accelerator, one

might want to think about it"—such an inspector might indeed have ASAT potential in its own right. Perhaps limits on the size, approach velocity, or capability of inspector satellites could be established.

Appendix A

Survivability of Space Capability

All panelists agreed that survivable space capability is important to the United States with or without an ASAT treaty. An irreducible residual ASAT threat will remain under any treaty, making survivability measures essential. Without a treaty, of course, satellites will face dedicated ASAT systems in addition to residual capability, making survivability requirements that much more difficult.

"Survivable space capability" includes measures both to protect and to supplement satellites. U.S. satellites have been hardened against nuclear effects and are spaced so that not more than one at a time should be vulnerable to any one nuclear explosion. Protection includes hardening against radiation, hardening against system-generated electromagnetic pulse (high voltages induced within components by radiation from nuclear explosions), and hardening against other nuclear effects. There are additional protective measures which can and should be applied to satellites to guard against non-nuclear threats. Satellites can be made to evade direct-intercept ASATs or space mines by maneuvering or by interfering with (jamming or confusing) the ASAT's homing sensors. In the absence of an ASAT ban, satellites could conceivably also be given active defenses.

Another way to protect satellites is to proliferate them. Various functions can be distributed on a wide variety of satellites, and duplicate satellites can be orbited. These spares can be left silent until needed and they can be decoyed, making their detection and destruction more difficult. One of the most important motivations for distributing capability is to buy time—it will take much longer to destroy many satellites with shared functions than it will take to destroy any single satellite. Proliferated systems should be simpler and more basic than the full-fledged, highly sophisticated equipment now used in military satellites. Non-space assets such as ground stations would have to be proliferated as well, with the proviso again that the proliferated stations not be as complex as the main ground station.

Satellites can also be replaced by other systems. Today, satellites are used in support of strategic forces but they are not essential. Ground-based radars can be used for early warning. Nuclear detonation detection, besides being proliferated onto many small satellites, can be done for our own warheads by placing transmitters on them, if needed. Tactical theater support now done with satellites can be replaced with a variety of systems —remotely piloted aircraft, sounding rockets, balloons, and low-cost replacement satellites launched on cheap boosters or ICBMs or SLBMs. There are many alternatives to space for functions which are now carried out in space.

Appendix B

Compliance With the 1972 ABM Treaty

The Reagan Administration's recent public allegations of Soviet non-compliance with arms control agreements have drawn much attention. One of these allegations concerned construction of a radar in Siberia which was said to be almost certainly in violation of the 1972 ABM treaty. This radar was discussed at one point in the workshop, and portions of that discussion are described in this appendix.

THE SOVIET RADAR NEAR KRASNOYARSK

According to Articles III and IV of the ABM treaty, ABM radars may be located only at agreed ABM sites or test ranges. Article VI notes that early warning radars may not be constructed except on the periphery of the country and looking outward. Agreed Statement F states that phased-array (electronically steered) radars greater than a specified size may not be deployed except as permitted by Articles III, IV, and VI. It goes on to exempt radars used "for the purposes of tracking objects in outer space or for use as national technical means."

The Soviets are constructing a phased-array radar of greater than the specified size near Krasnoyarsk in central Siberia. The location is not near the periphery of the country and it is not oriented outwards. If it is indeed an early warning or ABM battle management radar, the Soviets are in violation of the ABM treaty. The Soviets claim that the radar is allowable under the exemption in Statement F. Since it is geographically poorly sited to be effective for intelligence (national technical means) purposes, it would have to be a space track radar to be permitted under the treaty.

The administration has charged that this radar "almost certainly" violates the ABM treaty. Others find the issue somewhat less clear. The radar "sort of looks like a duck, and it walks a little bit like a duck, but it doesn't look quite like all the other ducks," in the words of one panelist. "The Soviets say, 'Oh, don't worry. It's not a duck. Notice there are some differences between it and other ducks, and when you hear it later, you'll find out it barks. It doesn't quack.' "

According to a panelist, the signal from a space track radar (a "dog") would be quite different from that of a radar used for ABM battle management (a "duck"). Therefore, the question will presumably be resolved when the radar becomes operational. However, some panelists were not willing to wait that long to find out, and they thought that the administration's announcement was proper. "You can't expect me to look at something that looks like a duck and walks like a duck and tell me it's a dog and I'm supposed to take it on faith. . . . You've got to provide more help than that." They felt that the Soviets were obligated to be more forthcoming about the radar than they had been within diplomatic channels, and that the public announcement served notice that the United States feels the issue has not adequately been resolved. Other panelists felt that existing channels were the appropriate forum and that the public announcement did not serve any constructive purpose.

Some panelists were generally skeptical as to whether the radar is in fact in violation of the ABM treaty. The utility of having such a flagrantly illegal early-warning radar, if it is one, was not felt to be sufficient incentive for the Soviets to unilaterally abrogate the ABM treaty. Others, including some who had access to intelligence data, had little doubt that the radar is indeed optimized for the ABM role. The alternative to being an illegal ABM radar is for the radar to be for tracking satellites, indicating a buildup of the Soviet space monitoring capability and being at least suggestive of an extension of their ASAT program.

BREAKOUT FROM AND LOOPHOLES IN THE ABM TREATY

The ABM treaty is under a great deal of pressure. In the United States, no ongoing research, development, or deployment contradicts treaty provisions. However, deployment of ballistic missile defense beyond the permitted single site would violate the ABM treaty, as would development, testing, or deployment of any ABM systems or components other than fixed, land-based ones. A panelist estimated that at the time of President Reagan's March 23, 1983 "Star Wars" speech, U.S. research into ground-based BMD components was about three years away from the point at which continuation could have run up against the ABM treaty. In light of the March 23 speech and

ensuing developments, this estimate may be lengthened to about a decade because more futuristic BMD technologies, which are highly immature, presumably will be emphasized at the expense of the older, more developed systems which were closer to deployment.

The Soviets, according to articles in *Aviation Week and Space Technology* referred to by workshop participants, are building defenses against tactical ballistic missiles. Since the ABM treaty prohibits defenses only against **strategic** missiles, anti-tactical ballistic missile (ATBM) systems are not covered and are therefore permitted. Anti-tactical ballistic missiles were not included in the ABM treaty at United States insistence in order to protect SAM-D, a surface-to-air missile then under development which was intended to have some capability against short-range tactical ballistic missiles as well as against aircraft. However, according to a panelist, as SAM-D developed (changing its name to 'Patriot'), "it lost not only its capability against missiles, but it lost much of its anti-aircraft capability" as well. At the same time, "the Soviets have essentially designed and deployed the 'SAM-D-ski', which looks a lot like what we were trying to protect."

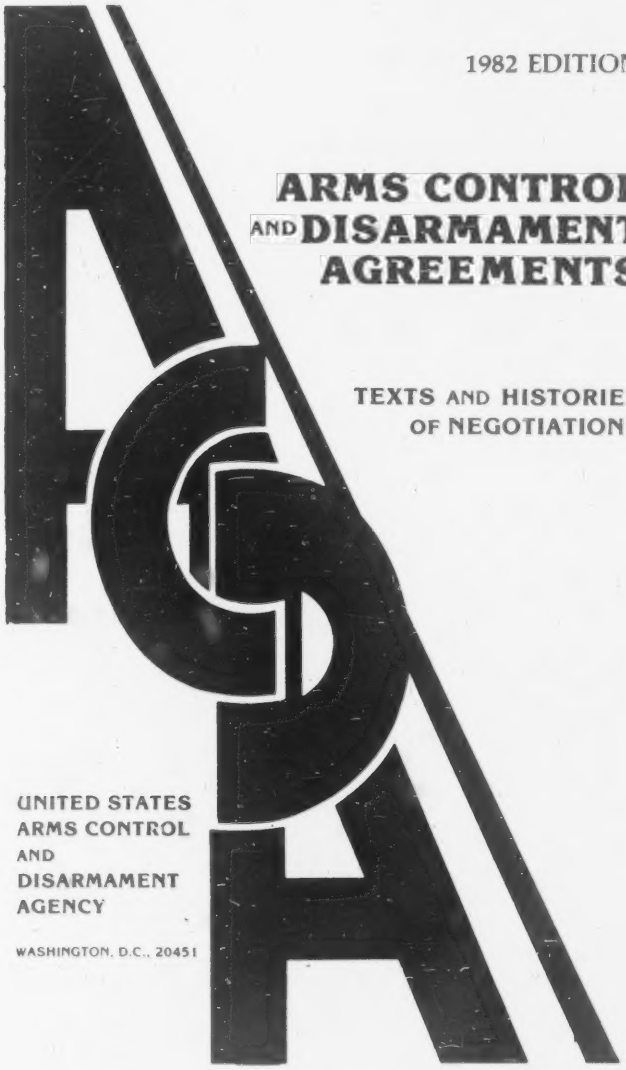
ATBM systems, and their impact on the continuing viability of the ABM treaty, were a source of considerable concern to many panelists. A panelist felt that "if things are deployed under the rubric of anti-tactical ballistic missiles, they can or will have an impact on the penetrability of our SLBMs and the French deterrent system and the British deterrent system, and the whole ball of wax can unravel." The U.S. deployment of Pershing II missiles in Europe could stimulate a particularly troubling Soviet ATBM deployment. 'The United States has no excuse for deploying anti-tactical ballistic missiles in its homeland," pointed out a participant, "but the Soviet Union does—and we're giving them a better one. We are now deploying an offensive system that says, 'Hey, you know those ATBMs? Come on, bring them out, there's a legitimate use for them now.' "

Panelists did note that, even if the Soviets should deploy extensive ATBM systems, it need not change the strategic balance. "We know how to deal with them," said one. "It requires penetration aids. We know how to do that." These aids are not presently deployed in the strategic inventory, which "we ought to do something about," but the United States is not in imminent danger of being effectively disarmed.

Another cause for concern is the continued miniaturization of components. Those who worry about possible scenarios in which the Soviet Union builds and stockpiles components in preparation for rapid breakout from the ABM treaty are worrying more now because small radars can have enough capability to fulfill some ABM roles. Even so, small radars cannot do so in the absence of large phased-array battle management radars. Since ABM battle management radars and space track radars share at least some characteristics, panelists felt that a radar clause might be required in an ASAT agreement to prevent circumvention of the ABM treaty restrictions on radars.

Appendix C

ABM Treaty and Related Documents



Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems

Signed at Moscow May 26, 1972
Ratification advised by U.S. Senate August 3, 1972
Ratified by U.S. President September 30, 1972
Proclaimed by U.S. President October 3, 1972
Instruments of ratification exchanged October 3, 1972
Entered into force October 3, 1972

The United States of America and the Union of Soviet Socialist Republics, hereinafter referred to as the Parties,

Proceeding from the premise that nuclear war would have devastating consequences for all mankind,

Considering that effective measures to limit anti-ballistic missile systems would be a substantial factor in curbing the race in strategic offensive arms and would lead to a decrease in the risk of outbreak of war involving nuclear weapons,

Proceeding from the premise that the limitation of anti-ballistic missile systems, as well as certain agreed measures with respect to the limitation of strategic offensive arms, would contribute to the creation of more favorable conditions for further negotiations on limiting strategic arms,

Mindful of their obligations under Article VI of the Treaty on the Non-Proliferation of Nuclear Weapons,

Declaring their intention to achieve at the earliest possible date the cessation of the nuclear arms race and to take effective measures toward reductions in strategic arms, nuclear disarmament, and general and complete disarmament,

Desiring to contribute to the relaxation of international tension and the strengthening of trust between States,

Have agreed as follows:

Article I

1. Each party undertakes to limit anti-ballistic missile (ABM) systems and to adopt other measures in accordance with the provisions of this Treaty.

2. Each Party undertakes not to deploy ABM systems for a defense of the territory of its country and not to provide a base for such a defense, and not to deploy ABM systems for defense of an individual region except as provided for in Article III of this Treaty.

Article II

1. For the purpose of this Treaty an ABM system is a system to counter strategic ballistic missiles or their elements in flight trajectory, currently consisting of:

(a) ABM interceptor missiles, which are interceptor missiles constructed and deployed for an ABM role, or of a type tested in an ABM mode,

(b) ABM launchers, which are launchers constructed and deployed for launching ABM interceptor missiles; and

(c) ABM radars, which are radars constructed and deployed for an ABM role, or of a type tested in an ABM mode.

2. The ABM system components listed in paragraph 1 of this Article include those which are:

(a) operational;
(b) under construction;
(c) undergoing testing;
(d) undergoing overhaul, repair or conversion; or
(e) mothballed.

Article III

Each Party undertakes not to deploy ABM systems or their components except that:

(a) within one ABM system deployment area having a radius of one hundred and fifty kilometers and centered on the Party's national capital, a Party may deploy: (1) no more than one hundred ABM launchers and no more than one hundred ABM interceptor missiles at launch sites, and (2) ABM radars within no more than six ABM radar complexes, the area of each complex being circular and having a diameter of no more than three kilometers; and

(b) within one ABM system deployment area having a radius of one hundred and fifty kilometers and containing ICBM silo launchers, a Party may deploy: (1) no more than one hundred ABM launchers and no more than one hundred ABM interceptor missiles at launch sites, (2) two large phased-array ABM radars comparable in potential to corresponding ABM radars operational or under construction on the date of signature of the Treaty in an ABM system deployment area containing ICBM silo launchers, and (3) no more than eighteen ABM radars each having a potential less than the potential of the smaller of the above-mentioned two large phased-array ABM radars.

Article IV

The limitations provided for in Article III shall not apply to ABM systems or their components used for development or testing, and located within current or additionally agreed test ranges. Each Party may have no more than a total of fifteen ABM launchers at test ranges.

Article V

1. Each Party undertakes not to develop, test, or deploy ABM systems or components which are sea-based, air-based, space-based, or mobile land-based.

2. Each Party undertakes not to develop, test, or deploy ABM launchers for launching more than one ABM interceptor missile at a time from each launcher, not to modify deployed launchers to provide them with such a capability, not to develop, test, or deploy automatic or semi-automatic or other similar systems for rapid reload of ABM launchers.

Article VI

To enhance assurance of the effectiveness of the limitations on ABM systems and their components provided by the Treaty, each Party undertakes:

(a) not to give missiles, launchers, or radars, other than ABM interceptor missiles, ABM launchers, or ABM radars, capabilities to counter strategic ballistic missiles or their elements in flight trajectory, and not to test them in an ABM mode; and

(b) not to deploy in the future radars for early warning of strategic ballistic missile attack except at locations along the periphery of its national territory and oriented outward.

Article VII

Subject to the provisions of this Treaty, modernization and replacement of ABM systems or their components may be carried out.

Article VIII

ABM systems or their components in excess of the numbers or outside the areas specified in this Treaty, as well as ABM systems or their components prohibited by this Treaty, shall be destroyed or dismantled under agreed procedures within the shortest possible agreed period of time.

Article IX

To assure the viability and effectiveness of this Treaty, each Party undertakes not to transfer to other States, and not to deploy outside its national territory, ABM systems or their components limited by this Treaty.

Article X

Each Party undertakes not to assume any international obligations which would conflict with this Treaty.

Article XI

The Parties undertake to continue active negotiations for limitations on strategic offensive arms.

Article XII

1. For the purpose of providing assurance of compliance with the provisions of this Treaty, each Party shall use national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.

2. Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this Article.

3. Each Party undertakes not to use deliberate concealment measures which impede verification by national technical means of compliance with the provisions of this Treaty. This obligation shall not require changes in current construction, assembly, conversion, or overhaul practices.

Article XIII

1. To promote the objectives and implementation of the provisions of this Treaty, the Parties shall establish promptly a Standing Consultative Commission, within the framework of which they will:

(a) consider questions concerning compliance with the obligations assumed and related situations which may be considered ambiguous;

(b) provide on a voluntary basis such information as either Party considers necessary to assure confidence in compliance with the obligations assumed;

(c) consider questions involving unintended interference with national technical means of verification;

(d) consider possible changes in the strategic situation which have a bearing on the provisions of this Treaty;

(e) agree upon procedures and dates for destruction or dismantling of ABM systems or their components in cases provided for by the provisions of this Treaty;

(f) consider, as appropriate, possible proposals for further increasing the viability of this Treaty, including proposals for amendments in accordance with the provisions of this Treaty;

(g) consider, as appropriate, proposals for further measures aimed at limiting strategic arms.

2. The Parties through consultation shall establish, and may amend as appropriate, Regulations for the Standing Consultative Commission governing procedures, composition and other relevant matters.

Article XIV

1. Each Party may propose amendments to this Treaty. Agreed amendments shall enter into force in accordance with the procedures governing the entry into force of this Treaty.

2. Five years after entry into force of this Treaty, and at five-year intervals thereafter, the Parties shall together conduct a review of this Treaty.

Article XV

1. This Treaty shall be of unlimited duration.

2. Each Party shall, in exercising its national sovereignty, have the right to withdraw from this Treaty if it decides that extraordinary events related to the subject matter of this Treaty have jeopardized its supreme interests. It shall give notice of its decision to the other Party six months prior to withdrawal from the Treaty. Such notice shall include a statement of the extraordinary events the notifying Party regards as having jeopardized its supreme interests.

Article XVI

1. This Treaty shall be subject to ratification in accordance with the constitutional procedures of each Party. The Treaty shall enter into force on the day of the exchange of instruments of ratification.

2. This Treaty shall be registered pursuant to Article 102 of the Charter of the United Nations.

DONE at Moscow on May 26, 1972, in two copies, each in the English and Russian languages, both texts being equally authentic.

FOR THE UNITED STATES OF AMERICA	**FOR THE UNION OF SOVIET SOCIALIST REPUBLICS**
RICHARD NIXON	**L. I. BREZHNEV**
President of the United States of America	*General Secretary of the Central Committee of the CPSU*

Agreed Statements, Common Understandings, and Unilateral Statements Regarding the Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missiles

1. Agreed Statements

The document set forth below was agreed upon and initialed by the Heads of the Delegations on May 26, 1972 (letter designations added).

AGREED STATEMENTS REGARDING THE TREATY BETWEEN THE UNITED STATES OF AMERICA AND THE UNION OF SOVIET SOCIALIST REPUBLICS ON THE LIMITATION OF ANTI-BALLISTIC MISSILE SYTEMS

[A]

The Parties understand that, in addition to the ABM radars which may be deployed in accordance with subparagraph (a) of Article III of the Treaty, those non-phased-array ABM radars operational on the date of signature of the Treaty within the ABM system deployment area for defense of the national capital may be retained.

[B]

The Parties understand that the potential (the product of mean emitted power in watts and antenna area in square meters) of the smaller of the two large phased-array ABM radars referred to in subparagraph (b) of Article III of the Treaty is considered for purposes of the Treaty to be three million.

[C]

The Parties understand that the center of the ABM system deployment area centered on the national capital and the center of the ABM system deployment area containing ICBM silo launchers for each Party shall be separated by no less than thirteen hundred kilometers.

[D]

In order to insure fulfillment of the obligation not to deploy ABM systems and their components except as provided in Article III of the Treaty, the Parties agree that in the event ABM systems based on other physical principles and including components capable of substituting for ABM interceptor missiles, ABM launchers, or ABM radars are created in the future, specific limitations on such systems and their components would be subject to discussion in accordance with Article XIII and agreement in accordance with Article XIV of the Treaty.

[E]

The Parties understand that Article V of the Treaty includes obligations not to develop, test or deploy ABM interceptor missiles for the delivery by each ABM interceptor missile of more than one independently guided warhead.

[F]

The Parties agree not to deploy phased-array radars having a potential (the product of mean emitted power in watts and antenna area in square meters) exceeding three million, except as provided for in Articles III, IV and VI of the Treaty, or except for the purposes of tracking objects in outer space or for use as national technical means of verification.

[G]

The Parties understand that Article IX of the Treaty includes the obligation of the US and the USSR not to provide to other States technical descriptions or blue prints specially worked out for the construction of ABM systems and their components limited by the Treaty.

2. Common Understandings

Common understanding of the Parties on the following matters was reached during the negotiations.

A. Location of ICBM Defenses

The U.S. Delegation made the following statement on May 26, 1972:

Article III of the ABM Treaty provides for each side one ABM system deployment area centered on its national capital and one ABM system deployment area containing ICBM silo launchers. The two sides have registered agreement on the following statement: "The Parties understand that the center of the ABM system deployment area centered on the national capital and the center of the ABM system deployment area containing ICBM silo launchers for each Party shall be separated by no less than thirteen hundred kilometers." In this connection, the U.S. side notes that its ABM system deployment area for defense of ICBM silo launchers, located west of the Mississippi River, will be centered in the Grand Forks ICBM silo launcher deployment area. (See Agreed Statement [C].)

B. ABM Test Ranges

The U.S. Delegation made the following statement on April 26, 1972:

Article IV of the ABM Treaty provides that "the limitations provided for in Article III shall not apply to ABM systems or their components used for development or testing, and located within current or additionally agreed test ranges." We believe it would be useful to assure that there is no misunderstanding as to current ABM test ranges. It is our understanding that ABM test ranges encompass the area within which ABM components are located for test purposes. The current U.S. ABM test ranges are at White Sands, New Mexico, and at Kwajalein Atoll, and the current Soviet ABM test range is near Sary Shagan in Kazakhstan. We consider that non-phased array radars of types used for range safety or instrumentation purposes may be located outside of ABM test ranges. We interpret the reference in Article IV to "additionally agreed test

ranges" to mean that ABM components will not be located at any other test ranges without prior agreement between our Governments that there will be such additional ABM test ranges.

On May 5, 1972, the Soviet Delegation stated that there was a common understanding on what ABM test ranges were, that the use of the types of non-ABM radars for range safety or instrumentation was not limited under the Treaty, that the reference in Article IV to "additionally agreed" test ranges was sufficiently clear, and that national means permitted identifying current test ranges.

C. Mobile ABM Systems

On January 29, 1972, the U.S. Delegation made the following statement:

Article V(1) of the Joint Draft Text of the ABM Treaty includes an undertaking not to develop, test, or deploy mobile land-based ABM systems and their components. On May 5, 1971, the U.S. side indicated that, in its view, a prohibition on deployment of mobile ABM systems and components would rule out the deployment of ABM launchers and radars which were not permanent fixed types. At that time, we asked for the Soviet view of this interpretation. Does the Soviet side agree with the U.S. side's interpretation put forward on May 5, 1971?

On April 13, 1972, the Soviet Delegation said there is a general common understanding on this matter.

D. Standing Consultative Commission

Ambassador Smith made the following statement on May 22, 1972:

The United States proposes that the sides agree that, with regard to initial implementation of the ABM Treaty's Article XIII on the Standing Consultative Commission (SCC) and of the consultation Articles to the Interim Agreement on offensive arms and the Accidents Agreement,[1] agreement establishing the SCC will be worked out early in the follow-on SALT negotiations; until that is completed, the following arrangements will prevail: when SALT is in session, any consultation desired by either side under these Articles can be carried out by the two SALT Delegations; when SALT is not in session, *ad hoc* arrangements for any desired consultations under these Articles may be made through diplomatic channels.

Minister Semenov replied that, on an *ad referendum* basis, he could agree that the U.S. statement corresponded to the Soviet understanding.

E. Standstill

On May 6, 1972, Minister Semenov made the following statement:

In an effort to accommodate the wishes of the U.S. side, the Soviet Delegation is prepared to proceed on the basis that the two sides will in fact observe the obligations of both the Interim Agreement and the ABM Treaty beginning from the date of signature of these two documents.

In reply, the U.S. Delegation made the following statement on May 20, 1972:

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[1]See Article 7 of Agreement to Reduce the Risk of Outbreak of Nuclear War Between the United States of America and the Union of Soviet Socialist Republics, signed Sept. 30, 1971.

The U.S. agrees in principle with the Soviet statement made on May 6 concerning observance of obligations beginning from date of signature but we would like to make clear our understanding that this means that, pending ratification and acceptance, neither side would take any action prohibited by the agreements after they had entered into force. This understanding would continue to apply in the absence of notification by either signatory of its intention not to proceed with ratification or approval.

The Soviet Delegation indicated agreement with the U.S. statement.

3. Unilateral Statements

The following noteworthy unilateral statements were made during the negotiations by the United States Delegation:

A. Withdrawal from the ABM Treaty

On May 9, 1972, Ambassador Smith made the following statement:

The U.S. Delegation has stressed the importance the U.S. Government attaches to achieving agreement on more complete limitations on strategic offensive arms, following agreement on an ABM Treaty and on an Interim Agreement on certain measures with respect to the limitation of strategic offensive arms. The U.S. Delegation believes that an objective of the follow-on negotiations should be to constrain and reduce on a long-term basis threats to the survivability of our respective strategic retaliatory forces. The USSR Delegation has also indicated that the objectives of SALT would remain unfulfilled without the achievement of an agreement providing for more complete limitations on strategic offensive arms. Both sides recognize that the initial agreements would be steps toward the achievement of more complete limitations on strategic arms. If an agreement providing for more complete strategic offensive arms limitations were not achieved within five years, U.S. supreme interests could be jeopardized. Should that occur, it would constitute a basis for withdrawal from the ABM Treaty. The U.S. does not wish to see such a situation occur, nor do we believe that the USSR does. It is because we wish to prevent such a situation that we emphasize the importance the U.S. Government attaches to achievement of more complete limitations on strategic offensive arms. The U.S. Executive will inform the Congress, in connection with Congressional consideration of the ABM Treaty and the Interim Agreement, of this statement of the U.S. position.

B. Tested in ABM Mode

On April 7, 1972, the U.S. Delegation made the following statement:

Article II of the Joint Text Draft uses the term "tested in an ABM mode," in defining ABM components, and Article VI includes certain obligations concerning such testing. We believe that the sides should have a common understanding of this phrase. First, we would note that the testing provisions of the ABM Treaty are intended to apply to testing which occurs after the date of signature of the Treaty, and not to any testing which may have occurred in the past. Next, we would amplify the remarks we have made on this subject during the previous Helsinki phase by setting forth the objectives which govern the U.S. view on the subject, namely, while prohibiting testing of non-ABM components for ABM purposes; not to prevent testing of ABM components, and not to prevent testing of non-ABM components for

non-ABM purposes. To clarify our interpretation of "tested in an ABM mode," we note that we would consider a launcher, missile or radar to be "tested in an ABM mode" if, for example, any of the following events occur: (1) a launcher is used to launch an ABM interceptor missile, (2) an interceptor missile is flight tested against a target vehicle which has a flight trajectory with characteristics of a strategic ballistic missile flight trajectory, or is flight tested in conjunction with the test of an ABM interceptor missile or an ABM radar at the same test range, or is flight tested to an altitude inconsistent with interception of targets against which air defenses are deployed, (3) a radar makes measurements on a cooperative target vehicle of the kind referred to in item (2) above during the reentry portion of its trajectory or makes measurements in conjunction with the test of an ABM interceptor missile or an ABM radar at the same test range. Radars used for purposes such as range safety or instrumentation would be exempt from application of these criteria.

C. No-Transfer Article of ABM Treaty

On April 18, 1972, the U.S. Delegation made the following statement:

In regard to this Article [IX], I have a brief and I believe self-explanatory statement to make. The U.S. side wishes to make clear that the provisions of this Article do not set a precedent for whatever provision may be considered for a Treaty on Limiting Strategic Offensive Arms. The question of transfer of strategic offensive arms is a far more complex issue, which may require a different solution.

D. No Increase in Defense of Early Warning Radars

On July 28, 1970, the U.S. Delegation made the following statement:

Since Hen House radars [Soviet ballistic missile early warning radars] can detect and track ballistic missile warheads at great distances, they have a significant ABM potential. Accordingly, the U.S. would regard any increase in the defenses of such radars by surface-to-air missiles as inconsistent with an agreement.

38-036 O - 84 - 88

Protocol to the Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems

Signed at Moscow July 3, 1974
Ratification advised by U.S. Senate November 10, 1975
Ratified by U.S. President March 19, 1976
Instruments of ratification exchanged May 24, 1976
Proclaimed by U.S. President July 6, 1976
Entered into force May 24, 1976

The United States of America and the Union of Soviet Socialist Republics, hereinafter referred to as the Parties,

Proceeding from the Basic Principles of Relations between the United States of America and the Union of Soviet Socialist Republics signed on May 29, 1972,

Desiring to further the objectives of the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems signed on May 26, 1972, hereinafter referred to as the Treaty,

Reaffirming their conviction that the adoption of further measures for the limitation of strategic arms would contribute to strengthening international peace and security,

Proceeding from the premise that further limitation of anti-ballistic missile systems will create more favorable conditions for the completion of work on a permanent agreement on more complete measures for the limitation of strategic offensive arms,

Have agreed as follows:

Article I

1. Each Party shall be limited at any one time to a single area out of the two provided in Article III of the Treaty for deployment of anti-ballistic missile (ABM) systems or their components and accordingly shall not exercise its right to deploy an ABM system or its components in the second of the two ABM system deployment areas permitted by Article III of the Treaty, except as an exchange of one permitted area for the other in accordance with Article II of this Protocol.

2. Accordingly, except as permitted by Article II of this Protocol, the United States of America shall not deploy an ABM system or its components in the area centered on its capital, as permitted by Article III(a) of the Treaty, and the Soviet Union shall not deploy an ABM system or its components in the deployment area of intercontinental ballistic missile (ICBM) silo launchers as permitted by Article III(b) of the Treaty.

Article II

1. Each Party shall have the right to dismantle or destroy its ABM system and the components thereof in the area where they are presently deployed and to deploy an ABM system or its components in the alternative area permitted by Article III of the Treaty, provided that prior to initiation of construction, notification is given in accord

with the procedure agreed to in the Standing Consultative Commission, during the year beginning October 3, 1977 and ending October 2, 1978, or during any year which commences at five year intervals thereafter, those being the years for periodic review of the Treaty, as provided in Article XIV of the Treaty. This right may be exercised only once.

2. Accordingly, in the event of such notice, the United States would have the right to dismantle or destroy the ABM system and its components in the deployment area of ICBM silo launchers and to deploy an ABM system or its components in an area centered on its capital, as permitted by Article III(a) of the Treaty, and the Soviet Union would have the right to dismantle or destroy the ABM system and its components in the area centered on its capital and to deploy an ABM system or its components in an area containing ICBM silo launchers, as permitted by Article III(b) of the Treaty.

3. Dismantling or destruction and deployment of ABM systems or their components and the notification thereof shall be carried out in accordance with Article VIII of the ABM Treaty and procedures agreed to in the Standing Consultative Commission.

Article III

The rights and obligations established by the Treaty remain in force and shall be complied with by the Parties except to the extent modified by this Protocol. In particular, the deployment of an ABM system or its components within the area selected shall remain limited by the levels and other requirements established by the Treaty.

Article IV

This Protocol shall be subject to ratification in accordance with the constitutional procedures of each Party. It shall enter into force on the day of the exchange of instruments of ratification and shall thereafter be considered an integral part of the Treaty.

DONE at Moscow on July 3, 1974, in duplicate, in the English and Russian languages, both texts being equally authentic.

For the United States of America:

RICHARD NIXON

President of the United States of America

For the Union of Soviet Socialist Republics:

L. I. BREZHNEV

General Secretary of the Central Committee of the CPSU

Office of Technology Assessment

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OTA Publishing Staff: John Bergling, Kathie S. Boss, Debra M. Datcher, Joe Henson, John C. Holmes

As the U.S. Administration pushes for lasers or particle beams as a defense against attacking nuclear missiles, the question is, could such a system be effective and reliable?

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Lasers for missile defense

In late March President Reagan called upon scientists "to turn their great talents to the cause of mankind and world peace: to give us the means of rendering . . . nuclear weapons impotent and obsolete." The President had in mind not the formulation of new arms control agreements with the Soviet Union, nor the invention of novel ways of verifying compliance with such agreements. He was considering instead the development of high energy laser beams and other weapons for launching the military into space. He was asking scientists to help create a new generation of strategic weapons.

The prospect of the militarization of space has met with little opposition, largely because lasers are advertised not as a mere weapon, but as an "anti-weapon weapon." Lasers, it is claimed, would protect the people of this country from a nuclear attack; they would put an end to the nuclear arms race and enable the United States to live in peace under a shield of light. The types of space lasers being discussed in the Senate and in industry, oddly enough, are only capable of shooting down a few satellites and perhaps a small fraction of attacking Soviet missiles. But, the argument goes, an anti-satellite laser would be a first step to a laser defense against missiles in 30 or 40 years.

The idea that lasers in space could defeat a nuclear attack is, however, fatally flawed. It is unlikely that any system of lasers, no matter how comprehensive, could destroy missiles with sufficient reliability to be regarded as the main component of a defense against nuclear attack. And even if it could, missiles are not the only means of delivering nuclear weapons. Moreover, putting in orbit a system of lasers big enough to begin to protect civilian targets from missile attack would require tremendous effort, most likely larger than any military project yet undertaken. Finally, the deployment of even a small laser system – despite its ineffectiveness as a defense – would create profound instabilities in the strategic balance between the United States and the Soviet Union.

A laser anti-ballistic missile (ABM) system would have several components: one or more high-energy lasers, mirrors to point and focus the laser beam, sensors to detect and locate missiles in flight, and a command system for firing the lasers. Advocates of a laser ABM system envision a number of "battle stations" orbiting the Earth and providing continuous coverage of its surface. Since it would be in space, the laser beam would not be absorbed by the Earth's atmosphere. Whenever the launch of a hostile missile was detected, the beam would be directed precisely in the direction of the missile. The shooting would occur during the "boost phase" of the missile's flight, which lasts for the first 250 seconds or so when the rocket is under power. The missile would be targeted during the boost phase for three technical reasons: During this phase, the target is relatively "soft," can be tracked by following the rocket's flame, and all of the MIRVed warheads can be destroyed at once.

The designer of a system of lasers for defense against ballistic missiles is faced with three fundamental constraints:

- Laser light, like any other light, beyond a certain distance decreases in intensity of power as the square of the distance from the source. Even in the vacuum of space, the range of any laser weapon is limited by this basic physical principle.
- The lower the orbit and range of a laser, the smaller the area of the laser's coverage. While three satellites in geosynchronous orbit of 30,000 kilometers could cover the Earth's whole surface, more than 200 would be needed if the lasers had a range of 1,000 kilometers. Because satellites in low orbit cannot hover over one spot, in order to cover all of the Soviet Union it is necessary to cover virtually the whole of the Earth's surface.
- For an effective defense, the laser system would have to be designed to deal with the worst case situation – the Soviets launching all of their approximately 2,000 missiles in a short time. A sufficient number of lasers would need to be in position over the Soviet Union at all times to be capable of shooting down the missile force. Thus, the number of lasers needed for an effective ABM becomes very large.

Contrary to popular notions, laser weapons do not vaporize the target. Instead, the energy in a laser beam weakens the skin of the missile, causing it to destroy itself by its own internal stresses. Missiles have a certain "hardness," which corresponds to the amount of energy per square centimeter which the laser must deliver to destroy the missile.

Although the details of laser systems now under consideration by the military are classified, it is possible, using the principles outlined above, to determine the size of a laser system needed to defend against a barrage launching of all Soviet missiles. We have done so for the two types of lasers most discussed in the Senate as candidates for a laser ABM. The "small" laser is a five-megawatt hydrogen fluoride laser with optics four meters in diameter. The "large" laser is a 10-megawatt hydrogen fluo-

Daniel Kaplan is a scientist with Battelle Pacific Northwest Laboratories in Washington, D.C. (20036). He was formerly associated with the Federation of American Scientists.

ride laser with 10-meter optics. Both are huge compared with present high-energy lasers, and the optics are not comparable in size and precision to any high-power mirror that has yet been built. (See accompanying table for a range of missile hardness.)

Number of Lasers Needed for Defense[a]

Laser type	*Missile hardness (joules per square centimers)*	*Number of lasers required*
small	soft (300)	760
	medium (2,000)	4,700
	hard (20,000)	Hard missiles cannot be destroyed by small lasers.
large	soft (300)	55
	medium (2,000)	400
	hard (20,000)	4,000

[a]Theoretical minimum number of lasers needed to defend against a concerted launching of 2,000 Soviet missiles.[1]

It has been estimated that each laser weapon would weigh 100 tons. If this is true, as many as 14,000 launches of the space shuttle would be required to place the lasers in orbit, and more launches would be needed to maintain them. Currently, fewer than 400 launches of the space shuttle are planned through 1992. The National Aeronautics and Space Administration (NASA) estimates that a substantial increase in the number of launches would cause considerable harm to the ozone layer.

This is not the whole story, however. Only about four percent of the laser satellites would be over the Soviet Union at any one time. It is these four percent that would shoot at Soviet missiles in the event of an attack; the other 96 percent would be out of range. Advanced military equipment is in service typically around 60 percent of the time. Assuming that the lasers would be 80 percent reliable—even though they would be more complicated than any of today's military equipment—there is still a good chance that some of those few satellites over the Soviet Union would not be working. In order to protect against a hole in the defense, it would be necessary at least to double the number of satellites in orbit.

Such a huge system of lasers is certainly not practicable. And in any case, even a system of this magnitude probably could not prevent tens or hundreds of MIRVed missiles from getting through, allowing hundreds or thousands of warheads to reach U.S. cities. To see why this is so, assume that a "perfect" defense system could be deployed—perhaps a laser system with a backup "conventional" ABM. In order to determine with any certainty that the system is, say, 98 percent effective, hundreds of missiles would have to be tested against it, an expensive and perhaps dangerous operation. And even if testing of this magnitude took place, it would not be under the full range of war conditions. Nor could tests take into consideration unknown Soviet advances in hardening missiles or disabling the laser system. Thus, however perfect the system appears on the drawing board, it is unlikely to be considered more than 98 percent effective. If the Soviets deployed no more missiles than allowed by SALT II, more than 400 warheads could still get through such a defense, enough to inflict huge damage.

Despite speculation that lasers could shift the emphasis of nuclear strategy from deterrence to defense, it is unlikely that a laser ABM could do more than supplement a deterrent force. A laser defense probably would be little more than another element in the sort of nuclear balance of terror that exists today. Not only is it likely that missiles can penetrate a laser defense; a defense against nuclear attack would also be incomplete without some means of protecting against low-flying bombers, cruise missiles and other low-altitude delivery systems. The atmosphere absorbs, scatters and defocuses laser light, affording a natural protection against lasers to weapons operating at low altitudes. Unless a means of countering these effects is developed, a laser ABM would be only a partial defense, even if it were completely effective against missiles.

In addition to using cruise missiles and bombers, it is possible to counter laser weapons directly. For instance, a laser could be destroyed—before or after it became operational—by exploding a nuclear bomb nearby in space. Or, space mines could be used, with satellites carrying explosive charges stationed nearby to destroy the lasers before they were functional. Some have claimed that by a combination of armoring the laser and using it to shoot down anything that threatens it, a laser could be protected against attack. However, this does not seem to be practicable. One reason is that a laser weapon must have large optics, which are necessarily susceptible to damage. An effective way of disabling a laser, therefore, would be to shoot at its optics with a wire mesh, sand, or ball bearings travelling at high speed. Because the projectiles would be small, and not contain sensitive explosives or guidance equipment, the laser would have to vaporize them—a very difficult task at the intensities usually discussed. Creating even a small chip in the mirror would cause the laser to destroy itself in a short time, since it would absorb its own energy. Thus, it would probably not be possible to defend against such anti-laser weapons except by denying entry into space to all suspicious satellites.

Because a laser defense would be a system, rather than a collection of independent parts, one means of attack would be to interfere with the links among the components. In any laser system, there would probably have to

Lasers, it is claimed, would put an end to the nuclear arms race and enable the United States to live in peace under a shield of light.

be a command communication link between Earth and the laser satellites. This link might be disrupted by many things, among them the electromagnetic pulse produced by nuclear explosions in the atmosphere. And even if the connection between ground and satellite were secure, it would still be possible to diminish the system's effectiveness by disrupting the coordination between laser satellites, since each laser would have to know what targets other lasers were shooting at, so as not to waste its own fire or let missiles through.

To aim at a target, a laser weapon would need detectors with their own large optics. Because the detectors would have to be highly sensitive in order to pick up the feeble signs of an ICBM in flight hundreds of kilometers away, they would be easy to interfere with. This could be done by blinding the detectors with a ground-based laser, by lighting flares to confuse the detectors, or by launching decoys. Since it is practically impossible to distinguish decoys from warhead-carrying missiles, lasers would have to spend valuable time shooting at decoys. Decoys might also induce aiming or tracking errors. Another possibility might be to build "stealth" missiles (just as Stealth bombers are being considered), or to hide the missile itself behind a screen, so that although it would be detectable it would not be targetable.[2]

As already mentioned, missiles can be hardened against laser light. Current Soviet liquid-fueled missiles might be vulnerable to as little as 300 joules per square centimeter of laser energy incident upon their surface, because the stress produced by the laser would combine with the stresses produced in the missile during launch. However, present-day re-entry vehicles (that is, the warheads themselves) are hardened to about 7,000 joules per square centimeter. This is a by-product of their being made to withstand both re-entry into the atmosphere and X-rays produced by nuclear explosions. One estimate is that the limit of ablative coatings – in which the protective shield flakes off as it heats up – is as much as 20,000 joules per square centimeter.[3] And there is no predicting what the limits of other missile hardening technologies may be. By rotating the missile in flight, the laser's energy could be more widely distributed over the missile surface, effectively increasing its hardness more than three times. Because techniques of missile hardening can be developed relatively quickly a laser defense would be subject to sudden obsolescence.

Excerpted from President Reagan's March 23 speech:

I am directing a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles. This could pave the way for arms control measures to eliminate the weapons themselves.

Whatever countermeasures have already been discovered, it is likely that efforts to find still better ones will be spurred on by continuing development of laser weapons. And the potential for development of countermeasures forces the designer of a laser system to find a way to obviate them, or to build another weapon which will fill in the gaps left by the laser.

Advocates of space lasers see them as essentially defensive, and claim that it is unlikely that deploying such a system would adversely affect the arms race or America's relation in general with the Soviet Union. But considering the structure of the nuclear balance, in which offensive weapons are designated as a deterrent to attack, the classification of a weapon as defensive is practically meaningless. The Soviets would probably view a U.S. laser system as offensive, in much the same way that Soviet civil defense plans are interpreted in the United States as a sign of Soviet aggressiveness.

For Moscow to look upon U.S. deployment of even a small system of lasers as a preparation for attack on the Soviet Union is not unreasonable. One mission well suited to a system of only a few laser weapons would be to cover a counterforce first strike – against strategic military forces, not civilian targets. The position of the military today is that the danger of a counterforce surprise attack can be greatly reduced by planning to launch the targeted missiles before the incoming missiles arrive: the tactic of "launch on warning." However, if four or five lasers were orbited – not nearly enough to *defend* against a surprise missile attack – their orbits could be coordinated so that they could cover all necessary targets within a certain time window.

These few lasers could be used to prevent missiles from being launched on warning during the half-hour interval of a counterforce attack; or, at least, so some military planners claim. And because of this capability to back up a counterforce strike, even a few lasers put into orbit could stimulate the arms race, just as the claimed development of accurate "silo-killing" missiles has done.

Another problem with space laser weapons is that they would have to be on hair triggers. To be effective, a laser would have to fire at a missile during the missile's boost phase. In a mass attack, the very size of the missile launch would be a clear indication of hostile intent. But if just one or two

Despite speculation that lasers could shift the emphasis of nuclear strategy from deterrence to defense, it is unlikely that a laser ABM could do more than supplement a deterrent force.

launches were seen, there would be a serious question as to whether they were for aggressive purposes or not. Because of the short time available to make a decision, unless there were a policy against using lasers except during mass launches, a peaceful satellite might be shot down by mistake.

This problem is deepened by the likelihood that space lasers would be mined. In order to counteract a U.S. laser, for instance, the Soviets might orbit an explosive device nearby, designed to destroy the laser when commanded to do so. Equally, the mines might be countermined. In any crisis, there would be a temptation to use one's mines before the other side did. The existence of space lasers might tend to escalate a crisis.

The most likely Soviet response to a U.S. laser system would be an increase in Soviet spending on cruise missiles and low-altitude bombers, weapons which are virtually immune to space lasers. But even though lasers are meant specifically to shoot down ballistic missiles, it may be that the most effective response to the deployment of a laser system would be to increase the numbers of ballistic missiles, or to take even drastic measures to harden missiles. For any of the laser systems considered above to compensate for an increase of, say, 25 percent in the size of the Soviet missile force, the number of lasers in orbit would have to be raised by 25 percent.[4] Similarly, doubling the hardness of missiles would require doubling the number of lasers.

It is a mistake to consider the cost of a laser system as a one-time expense which can be borne without regard to the economies involved. If it costs more to shoot down a missile than to add one to the missile force, then the United States would probably lose a laser *versus* missile race. Of course, the Soviets might find it less expensive to harden old missiles, or to build cruise missiles or bombers, than to add new ballistic missiles.

Supporters of space lasers tend to view them as a kind of ultimate weapon. They feel that whichever nation first deploys them will not only be able to protect itself against nuclear attack, but control space as well. Senator Malcolm Wallop of Wyoming, a prime supporter of laser weapons, expresses the fear that "as the Soviet Union perfects the kind of space-based laser system that can deny one or two missiles entry into space, we will have to tell them in detail the payload of everything we send up from there on, or they will shoot it down, treaty or no treaty, and we may never get to deploy [our own lasers]."[5] Wallop urges the military to increase its research efforts so that a laser system can be deployed in five or 10 years. This, he says, would enable the United States to prevent the Soviet Union from orbiting its own lasers. Wallop succeeded in getting a bill passed which adds $50 million to the 1982 budget for space laser research, and this was a compromise. His original intention was to add $250 million to the research budget and stipulate that a prototype weapon be built by 1985. Yet most experts think that it will be at least 20 years before working space laser weapons can be built, and some believe it simply cannot be done.

Official Pentagon policy is to proceed with the development of lasers, large-scale optics and other equipment associated with a space-based laser weapon, but not to direct effort toward construction of prototype weapons. This policy allows the United States to maintain its position technologically with respect to the Soviets, helps determine what sorts of laser missions are and are not practicable, provides a basis for assessing Soviet technology, and gives the potential for warning of a Soviet breakthrough in laser technology. The budgets for laser research in the Air Force and the Defense Advanced Research Projects Agency have increased steadily to a total in 1983 of about $470 million, and they are expected to increase more rapidly in the future. Contracts have already been let to assess the vulnerability of missiles to laser light, to design pointing and tracking devices for lasers, and to develop large-scale optics.

While the Pentagon has given no indication of intending to build a prototype weapon, defense contractors are more ambitious. Lockheed Missiles has already unveiled a model of a space-based laser weapon, though it seems to have more publicity than technical value.

In the past, military projects have often proceeded despite a lack of strategic or technological justification. Sometimes, as with the nuclear-powered airplane, the only result was wasted money. Other times the price has not been so cheap: The ABM missile project has come and gone but MIRV—which was justified as a means of countering ABM—is a permanent legacy of escalation. Space lasers also have the potential to escalate the arms race and expand it into space. This potential completely dwarfs the benefits lasers might bring as a defense against missiles. □

1. These figures were arrived at through a calculation involving the power of the laser, its distance from the target missile, the hardness of the target, and the need, in theory, to be able to destroy 2,000 missiles that might be launched in an all-out enemy attack. The optimal altitude for a 10-megawatt, 10-meter diameter laser turns out to be 150 kilometers; however, this altitude leads to an unstable orbit. The given figures are based on an altitude of no less than 250 miles. For details on how the calculation was done, please contact the author.

2. See, for example, Richard Garwin, "Are We on the Verge of an Arms Race in Space?," *Bulletin* (May 1981), pp. 48-53.

3. *Aviation Week and Space Technology* (Feb. 16, 1981), p. 17.

4. This is because lasers, in most cases, could not be stationed at their theoretically optimal altitudes. See note 1.

5. Congressional Record (July 1, 1980), at S9075.

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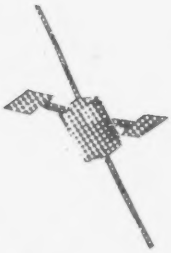

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Space Weapons

History and current debate

Richard Garwin and John Pike

Effect on strategic stability

Yevgeny P. Velikov

*President Reagan's proposal to create a comprehensive space-based anti-missile defense system has been vigorously challenged by scientists on technical as well as strategic, political and even moral grounds. Richard L. Garwin has been prominent among the challengers. In February 1983 he and Carl Sagan authored a petition urging the United States, the Soviet Union and "other space-faring nations" to agree to ban weapons of any kind from space and in particular "to prohibit damage to or destruction of satellites of any nation"—a petition signed by dozens of other leading U.S. scientists (*Bulletin, *November 1983).*

In the following article Garwin and John Pike provide a comprehensive argument against the Reagan proposal, concluding with an urgent call for negotiations. Their article is followed by one from Academician Yevgeny P. Velikhov of the Soviet Union. While agreeing in essence with the Garwin-Pike analysis, Velikhov also calls for a diversion of funds from weapons research into such joint U.S.-Soviet projects as space exploration.

Several prominent scientific organizations share the Bulletin's *concern with the militarization of space and either have published or are preparing studies of the military uses of space. A joint project of the Brookings Institution and the Massachusetts Institute of Technology has recently resulted in a book,* Ballistic Missile Defense. *In late March the Union of Concerned Scientists released the 106-page report of a study panel,* Space-Based Missile Defense. *The Federation of American Scientists has now made available a book-length study,* Anti-Satellite Weapons: Prospects and Implications. *The American Physical Society has established a task force to study and evaluate directed energy weapons. And finally, the American Academy of Arts and Sciences has begun a study of weapons in space, which is to be ready for publication by the end of this year. The* Bulletin *will continue to report on problems and developments in this area.*

History and current debate

by Richard L. Garwin and John Pike

THE QUESTION of space weaponry has become more urgent and much more widely discussed since one of the authors last wrote about the subject in these pages.[1] Two types of concerns are evident—those connected with anti-satellite capabilities and activities (ASAT) and those connected with global defense against ballistic missiles. This article will survey these two topics and their important, but limited interaction. Our conclusion, based upon many years of involvement with strategic offensive weapons, strategic defenses and military space systems, is that an effective ban on anti-satellite activities and capabilities and on weapons in space would best serve the national security interests of the United States. Furthermore, an effective ban is feasible and can be negotiated quickly.

Overview: history and present status

For the past 25 years, space weapons have remained largely in the realm of speculation. With President Reagan's Star Wars speech of March 23, 1983, their discussion assumed a certain immediacy, but underlying developments are equally to blame. Space weapons include systems that either are based in space or are intended for use against targets in space, such as satellites. In the past, the poor performance of such systems made it rather difficult to identify useful military missions for them. Now present and prospective improvements in sensor and computer technology, as well as in kill-mechanisms such as directed energy systems, have encouraged a reexamination of the case for space weapons.

Richard L. Garwin is adjunct professor of physics, Columbia University and a fellow at the IBM Thomas J. Watson Research Center, Yorktown Heights, New York (10598). He has been working on defense issues and military technology for over 30 years.

The technology of space weapons might have changed, but the strategic and political questions concerning them have not. It is important to ask whether any missions for space weapons would result in a net improvement in U.S. national security or in the prospects for peace.

During the 1960s both the United States and the Soviet Union developed anti-satellite systems with marginal capabilities. Because of their limitations, and because of the newfound value of satellites themselves, these systems generally did not attract much interest.

The two early U.S. ASAT systems suffered from several common defects. Deployed in very small numbers, they were capable of rather modest rates of fire, and their limited range meant that they had to wait for an intended target to pass within a few hundred miles of their base before an interception could be attempted. The use of high-yield nuclear warheads furthermore posed the risk of considerable collateral damage to friendly satellites. Neither of their potential missions—defense against Soviet orbital nuclear weapons and deterrence or defeat of Soviet attacks on U.S. reconnaissance satellites—seemed particularly compelling by the early 1970s.

Although the early history of Soviet ASAT efforts remains clouded by official secrecy, their capabilities seem no more than slightly behind those of the United States. A clear indication of Soviet work in this area came in 1968, with the initial test of an orbital ASAT, colloquially known as a "killer satellite," reminiscent of the abandoned U.S. SAINT

(Satellite Inspection Technique) program. The Soviet ASAT is launched by a modified version of the SS-9 ICBM. The intercept vehicle itself has a mass of 2,300–3,300 kilograms, and 1,000 kilograms of maneuvering fuel would give it a maneuvering velocity change of as much as one kilometer per second. The system has been tested 20 times, using a variety of trajectories that take from 45 minutes to several hours from launch to intercept, reported at a maximum altitude of 2,300 kilometers. Initial tracking of the target is reported to use ground-based radars. An on-board active radar guidance system achieved 10 successes in 14 attempts. Beginning in 1976, a more sophisticated passive system, perhaps using an optical sensor, has been tested six times with no more than one success. Several types of payloads might have been carried on the interceptor.

In 1979, Air Force Chief of Staff Lew Allen characterized the Soviet ASAT as "having a very questionable operational capability." The variety of anti-satellite components and techniques, as well as the fitful and irregular pace of the tests, suggest that the program is as much an effort to develop a generic military technology as it is to deploy a weapon to counter a specific set of targets. The limited maneuvering capabilities require that it be placed into an orbit that is generally similar in inclination to that of its intended target. Thus the interceptor cannot be launched until the orbital ground track of its target passes to within a few hundred kilometers of the launch facility. This requirement may not be satisfied for several hours, even as long as a day, after a decision has been made to conduct an intercept. The small number of launch pads available for ASAT launches imposes a further operational limitation.

The present Soviet ASAT potentially threatens low-flying U.S. space assets, including photographic reconnaissance satellites and the Transit navigation satellites. However, most important U.S. satellites, such as those used for early warning and communications, are in geosynchronous orbit (GEO) at 36,000 kilometers above the Earth—far beyond the demonstrated range of the Soviet ASAT. The threat to satellites in lower orbits will decline in coming years, as various survivability programs for them are implemented, such as the transfer of the navigation support mission to the Navstar satellites, which orbit at an altitude of 20,000 kilometers.

DURING the 1970s both countries greatly increased their reliance on space to support conventional and strategic forces on Earth. In the absence of restraint these numerous military support satellites could be an incentive to develop new and more capable ASATs in order to reduce enemy military effectiveness, with serious negative implications for both crisis and arms-race stability.

The Soviet resumption of ASAT testing in February 1976, after a pause of over five years, was the proximate impetus for the development of the new U.S. ASAT, initiated in the closing days of the Ford Administration. Major ASAT funding increases had been proposed prior to the resumption of Soviet testing, and the Carter Administration subsequently concurred in this decision as part of a multi-pronged effort that included programs to enhance the survivability of military satellites and negotiations with the Soviet Union to limit ASATs.

The ASAT configuration chosen for development is the Air-launched Miniature Homing Vehicle (ALMV), delivered by a small two-stage rocket to be carried on an F-15 fighter aircraft. The SRAM (Short-Range Attack Missile) first stage and the ALTAIR-III second stage would be launched from the F-15 guided by a programmed-inertial guidance system, to intercept a satellite whose orbital parameters had been determined by ground-based sensors. Weighing about 1,200 kilograms, the F-15 launched rocket would boost a Miniature Homing Vehicle (MHV) which would maneuver to intersect the target satellite's orbit, destroying the target on impact.

The maximum altitude at which the ALMV can attack satellites may be in the range of 2,000 kilometers. Whatever the "reach," or cross-range capability, of the ASAT, the F-15 can carry it to launch points several thousand kilometers from the home air base. With the use of mid-air refueling and basing at forward facilities such as Diego Garcia or Ascension Island, the ALMV could be used to attack low-altitude satellites at almost any point in their orbit. This system will be capable of attacking a wide range of Soviet military satellites, including all their photographic and electronic intelligence satellites, the Radar Ocean Reconnaissance Satellites (RORSATs), and the *Salyut* space station. Communication and early warning satellites in highly elliptical 12-hour *Molniya* (lightning) orbits can be attacked at the low points in their orbits, which are over the Antarctic Ocean. This would require forward basing of the F-15 at Diego Garcia, Ascension Island or North West Cape, Australia, as well as aerial refueling.

The first flight test of the ALMV booster was on January 21, 1984. The first test of the system against a target in space will come at the end of 1984, and at least ten additional such tests are planned before the system becomes operational in 1987. Over 100 interceptor rockets are scheduled for procurement at a total cost of $3.6 billion, although this cost is expected to increase. About 50 F-15s will be modified to carry the ASAT, permitting the entire arsenal of interceptors to be fired within a few hours.

To the extent that the United States or the Soviet Union depends or is believed to depend on satellites for strategic deterrent capability, acquisition by either country of an ability to destroy the opponent's early-warning, communication and navigation satellites could provide an incentive to initiate an anti-satellite campaign that would greatly degrade the capabilities of the opponent's military forces. Should *both* countries achieve such a capability, each would have considerable incentive to initiate preemptively such a

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John Pike, associate director for space policy at the Federation of American Scientists in Washington, D.C. (20002), is the convenor of the Space Policy Working Group, which coordinates legislative activities on space weapons, and is author of several studies of space weapons.

courtesy Department of Defense

An F-15 plane equipped with anti-satellite weapons (ASAT), currently being tested by the U.S. military.

campaign during a time of acute crisis. Both instances would decrease crisis stability and increase the threat of war. If a strategic defense, especially a perfect or disarming one, depends on satellites, those satellites are at particular risk. The possibility that accidental malfunctions of vulnerable satellites could exacerbate an on-going crisis also cannot be ignored.

Today we are confronted by the third generation of anti-satellite weapons. The early U.S. ASATs, flying short ballistic trajectories to deliver nuclear warheads, were soon followed by the more advanced Soviet ASAT, which orbits a conventional explosive charge that maneuvers to within range of its target. Now the United States has begun testing an even more advanced air-launched system. In the absence of mutual restraint, it can only be a matter of time before both countries field even more capable systems, thus placing arms race stability at risk.

More advanced ASATs may pose increasingly serious challenges to the 1972 ABM Treaty. U.S. (and presumably Soviet) ASATs have incorporated technologies derived from ballistic missile defense systems. In the future, systems that were nominally for anti-satellite purposes could be used to approach ballistic missile defense capabilities that are otherwise prohibited by the ABM Treaty. The more capable ASATs of one side might create such suspicions on the other, raising the specter of a gradual erosion of the Treaty regime under the guise of an ASAT competition.

President Reagan's Star Wars speech, however, has posed a more immediate challenge to the ABM Treaty. Although the Administration has proposed no immediate abandonment of the Treaty, a number of likely development and test programs may raise questions of compliance with the letter of the Treaty. More important, if the doctrinal implications of the President's initiative gain general acceptance in the United States, the demise of the Treaty will soon follow. Under these circumstances, the Soviet Union can hardly be expected to sit back and wait for the United States to choose a convenient time to announce its renunciation.

The strategic and political rationale of the ABM Treaty was developed in an era of technology that both superpowers have now surpassed. But technological innovation does not invalidate that rationale, nor lessen the Treaty's importance. No ABM system in prospect could provide a perfect defense against attack. Such systems are subject to passive and active countermeasures, including direct attack on the defensive system itself, and a ballistic missile defense system which seems promising against the existing strategic offensive force may be defeated at little cost. A ballistic missile defense system would be much more effective in defending against a small and disorganized retaliation than it would in defeating a massive and well-organized first strike. This disparity would provide incentive for preemption (by either side) that would undermine crisis stability.

Arms-race stability would also suffer, as the most straightforward countermeasures would be a simple proliferation of offensive arms. Since each country would tend to overestimate the effectiveness of the opponent's defensive system, while underestimating the effectiveness of its own defenses, conservative planning would generate ever higher requirements for offensive forces. There is no rational upper limit to this competition, save perhaps the carrying capacity of the country's economy.

These systems would require funding on an unprecedented scale. Various estimates place the cost of two layers of ground-based ABM systems at $200 billion, and the cost of the space-based component at perhaps $500 billion. To these costs should be added those of continental air defense and civil defense, which would push the cost of the total strategic defense package to over $1 trillion.

These estimates, however, do not fully capture the magnitude of the problem, since such defensive systems will have to be maintained, modified and upgraded in response to the changing and inexorably expanding offensive threat. What is really under discussion is the addition of perhaps $100 billion annually to the defense budget, perhaps as soon as the mid-1990s. Given the negative impact on crisis and arms-race stability of strategic defensive systems, it is difficult to see the justification for expenditures of this magnitude.

Prospects

In most important respects the new U.S. ASAT constitutes an order of magnitude improvement over the existing Soviet ASAT. The flight time from launch to intercept is one-tenth as long. The total number of interceptors will be ten times greater. The Soviet ASAT booster is ten times the size, and 100 times the mass of the U.S. ASAT booster, and the disparity between the sizes of the actual intercept vehicles is even greater.

It is clear, however, that the new U.S. ASAT is not the last word in weapons of this sort. In the absence of negotiated restraint, both the United States and the Soviet Union are likely to develop even more capable anti-satellite weapons, which will share two disturbing characteristics: the ability to attack satellites in high orbits and an increasing resemblance to anti-ballistic missile systems. Both are good reasons for precluding the development of such weapons.

The United States has already studied several advanced ASATs that would use the Miniature Homing Vehicle and more capable boosters. A larger air-launched booster rocket could extend the range of the F-15 system so that it could attack satellites at an altitude of several thousand kilometers. Above this range, the advantage of using air-launching to match the orbital ground track of the target diminishes. Satellites at higher altitudes could be attacked by launching the MHV atop a larger rocket, such as the Minuteman

or the Trident. These systems could be developed in a few years time, at a cost of several billion dollars.

A transfer from low Earth orbit (LEO) to inject into GEO with minimum additional energy requires a velocity increase of 3.6 kilometers per second -- about a factor three increase in launch weight (or a factor three reduction in available payload). This does not include the plane change required if one insists on *co-orbital* trajectory; that amounts to almost another factor two if one starts with an orbital inclination of 60 degrees corresponding to Soviet launch latitudes. The flight time from launch to interception of satellites at semi-synchronous or geosynchronous orbits would be several hours, permitting evasive maneuvering by the target. Such long flight times would also result in loss of surprise, which is important for attacks on targets such as early-warning satellites.

Thus the use of directed energy weapons has attracted some attention. These weapons could be either ground-based or space-based. Published reports suggest that the United States could test a ground-based laser against targets in geosynchronous orbit by the end of this decade. Tests of a space-based laser of somewhat lesser range could begin by 1992. However, this space laser would pose serious questions concerning compliance with the 1972 ABM Treaty, and thus no decision has been made to conduct such a test.

The Soviet Union could also introduce a variety of improved ASATs. With continued testing, they will eventually perfect the thus far unsuccessful passive optical guidance for their present ASAT. Because the general trend in the Soviet ASAT program has been toward reducing the flight time from launch to interception, we might expect to see the introduction of a non-orbital "pop-up" ASAT, which would intercept its target within a few minutes after launch. The present Soviet system could be used in this mode if it were provided with a guidance system capable not only of bringing it to a specified point in space, but also at a specified time. Large ground-based radar could be used to overcome target countermeasures such as maneuvering, jamming or decoys. These radars could also be used in support of an air-launched system similar to the new U.S. ASAT, which could use planes such as the Foxbat fighter or the Blackjack bomber as launch platforms. Such systems would pose serious problems for verification of a treaty that included a ban on deployment.

For several years Defense Department officials have reported that the Soviet Union might soon launch a large laser into orbit. Given the pace and schedule of the U.S. space laser program, the state of Soviet work in this field and the Soviet tendency to move to field testing of prototypes at an earlier stage than is the case in U.S. programs, this prediction is not unreasonable. It tends to create the impression that a Soviet space laser would convey a military benefit, which is not the case. Nevertheless, testing of a space-based weapon would be regarded as development of a space-based ABM system, specifically banned by the ABM Treaty.

IN HIS MARCH 23, 1983 speech, President Reagan asked "the scientific community in our country . . . to turn their great talents now to the cause of mankind and world peace: to give us the means of rendering these nuclear weapons impotent and obsolete. . . . I am directing a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles." And on March 27, 1983, Secretary of Defense Caspar Weinberger said on the "Meet the Press" television program, "The defensive systems the President is talking about are not designed to be partial. What we want to try to get is a system which will develop a defense that is thoroughly reliable and total, yes. And I don't see any reason why that can't be done."

The President and the secretary are clearly talking about "assured survival," as an alternative to deterrence of nuclear war by threat of retaliation. But to eliminate the fear of nuclear weapons, even of delivery of nuclear weapons by ICBMs, in the presence of the almost 10,000 strategic reentry vehicles on either side, is more than we believe the United States or the Soviet Union can accomplish. ICBMs take about 30 minutes to fall to their targets, as do submarine-launched ballistic missiles (SLBMs) of intercontinental range. Shorter-range SLBMs and the notorious intermediate-range nuclear forces (INF) may take ten minutes. Thus to be useful against ballistic missiles a system must do its job within 30 minutes or not at all. A space-based defense which would prevent 50 percent of the reentry vehicles from landing would be doing a pretty good job; one which prevented 90 percent would be an active defense beyond experience. Yet achieving even such defenses would simply result in the elimination of some of the marginally useful targets for nuclear weapons and would focus the remainder (for

Figure 1. Destructive mechanisms

Mechanism	*Device*	*Operation*
Pulsed laser	X-ray laser Excimer laser	Deliver a high impulse or shock to a missile to break or blow a hole in it and cause structural collapse of the booster
Continuous wave laser	Free electron laser Excimer laser Hydrogen fluoride/ deuterium fluoride laser	Stay on target until a hole is burned through it, then switch to another target
Continuous particle beam	Neutral particle beam	Destroy internal weapon components
Mass accelerator	Kinetic energy rail gun	Accelerate small homing hit-to-kill vehicles (non-nuclear kill)
Self-propelled missile	Miniature homing vehicle	Infrared sensor senses spot of radiation from incoming re-entry vehicle. Homes in and destroys with hit-to-kill vehicle

Source: Department of Defense, as cited by Richard D. DeLauer, undersecretary of defense for research and engineering, in his testimony before the House Armed Services Committee, Nov. 10, 1983.

deterrence or for "compellence") on the society's centers of value—industry and population.

Recognizing the difficulty or impossibility of having any system which will provide 99.99 percent protection (to reduce the expected number of warheads striking their targets to less than one), advocates of such programs rely on arithmetic, asserting that a defense of four totally independent layers, each of which allows only 10 percent of the incoming weapons to leak through, will allow an average of only one in 10,000 weapons through all four layers. This assumes that there are no common-mode failures (that is, if a reentry vehicle leaks through one layer, it will automatically leak through another) in which case the number leaking through increases by a factor 10, 100 or 1,000. Furthermore, the *assumption* of four layers, each with 10 percent leakage, does not guarantee the existence of even *one* such layer. Finally, if four independent defenses can be found which are compatible with layering, all four must be paid for, maintained, and not allowed to interfere with one another.

For 20 years the fact that one can "hit a bullet with a bullet" has not solved the ballistic missile defense problem. That solution requires not only the application of science and technology but also the assurance that the scientists, technologists and investors of the other side will not be able to *counter* the defenses. The fact that one nuclear warhead can kill a million people and do at least $100 billion worth of property damage makes it very important to prevent access by even one reentry vehicle. Obviously it is essential to know whether such a perfect defense is possible. A nation possessing such a defense need not be deterred from destroying its adversary, since it could protect totally against retaliation in case it launched a nuclear attack. Of course, not only the feasibility but also the *counterability* of such a defense is important, and neither side need promise to lie down and play dead if the other side develops and deploys a defense which promises to be effective against the "unadapted" force.

We went through this in the 1960s, when U.S. perceptions of the emergence of a ballistic missile defense by the Soviet Union led Secretary of Defense Robert McNamara to authorize the development of MIRVed Minuteman missiles, thereby countering the nascent Soviet ballistic missile defense and increasing greatly the flexibility of the U.S. strategic offensive force and the threat to the Soviet Union.

What is new? Not the desire to feel free from the threat of destruction! That is as old as human beings, and many have availed themselves of that desire by retreating to a world of unreality. New are the existence of high-speed flexible computation in small packages; optical lasers for viewing and for concentrating potentially damaging radiation at a distance; complex focal-plane arrays for viewing large areas with reasonable resolution; and the prospect of the soft X-ray laser pumped by a nuclear explosion which can hope to focus one one-thousandth or one ten-thousandth of the energy of a nuclear weapon into one-millionth or one-billionth of the sphere, corresponding to an increase of X-ray intensity over that provided by the same nuclear explosion by a factor 100 or 1,000 (or 100,000 or one million).

Furthermore, a ten-fold larger nuclear weapon exploded at 1 percent of the distance would correspond to a 100,000-fold increase in intensity over the reference weapon, so that there is a tradeoff (assuming operationally and technically feasible X-ray lasers) between their use and the pre-deployment of X-ray defenses. In fact, the X rays from a nuclear explosion may be much more effective than those from an X-ray laser, for the same energy delivered to the target.

ANY SUCCESSFUL manager or leader strives to eliminate potentially unsuccessful candidates as quickly as possible, and if defensive systems can be shown to be vulnerable, that is as good a way to eliminate them as showing them to be technically infeasible. Because defensive systems are far more complicated than offensive systems, the offense has time to adapt to a defense of potentially great effectiveness.

Thus the United States has long done major research and field testing on penetration aids against terminal and midcourse ballistic missile defense. It may not carry those "penaids" on its ICBMs and SLBMs since it is confident that no such defenses exist. Nevertheless, if the Soviet Union initiated a multi-year deployment of ballistic missile defenses the United States certainly would have pen-aids ready in time. At the cost of a small fraction of the warheads now carried on the strategic offensive force, the remaining warheads would have a high probability of penetration to their targets. An estimate of the penetration probability of the *unadapted* force might yield a totally different result, but it would not be relevant.[2]

Midcourse intercept of reentry vehicles continues to be frustrated by the feasibility of balloon decoys to fool radar and infrared and optical sensors.

The boost phase of an adapted offensive force lasts a short time (40–100 seconds), and defensive systems stationary with respect to the likely launch areas are either based on the Earth, in its atmosphere or in GEO (in any case 10,000 or 40,000 kilometers from the launch). It is thus not possible to attack with rocket-propelled defenses, unless the rockets can be fired *before* ICBM or SLBM launch, in confidence that the offensive weapons will be launched only to be destroyed! Considering systems based in orbit, cross-track capability out to 250 kilometers could be obtained from vast numbers of small interceptors which burn 90 percent of their initial mass as rocket fuel, but some 3,000 would be required in orbit to have one close enough to destroy a single ICBM. If no more than 100 silos are located within a circle 500 kilometers in diameter, 300,000 of these orbital rockets would be required even if they were 100 percent effective and reliable. (Of course, a mere 3,000 "space trucks" each carrying 100 interceptors could do the job, but they would be vulnerable to space mines.)

As for beam weapons, a simple calculation shows that a fluence (energy per unit area) exceeding ten kilojoules per square centimeter is required to damage a rocket booster which has been modified to survive against optical or X-ray lasers. For optical lasers, we have the usual tension bet-

ween basing in synchronous orbit (at some 40,000 kilometers from their targets and viewing the ICBM or SLBM launch sites all the time), and basing them in LEO, where they could use effective ranges as short as 1,000 kilometers. But in LEO they would have to reckon with the facts that the Earth's surface area is 500 million square kilometers and that the area coverable by a weapon at 1,000 kilometers is only 3 million square kilometers. If the effective range of a laser were to be taken as 1,000 kilometers instead of 40,000 kilometers, its power need be only one sixteen-hundredth as great (or its mirror diameter one-fortieth as large), but it would have to slew over a much wider angle to catch all the boosters within its purview, and 170 lasers in LEO would put only one within range of a particular launch. Furthermore, any laser would have to be able to destroy as many as several hundred boosters during the couple of minutes of boost phase.

Assuming the existence of one-megawatt lasers in the midwavelength range (perhaps three microns) and a boost phase for an adapted strategic offensive missile of 120 seconds, a laser could destroy *one* ICBM if it illuminated it for 100 seconds at a power of 100 watts per square centimeter to meet the assumed kill criterion of 10 kilojoules per square centimeter. At this wavelength, however, a mirror three meters in diameter would provide a spot 100 meters in diameter and the intensity from a 100-megawatt laser would be only *one* watt per square centimeter instead of the required 100. Therefore to destroy even a single ICBM in boost phase from GEO would require an optically perfect mirror 30 meters in diameter and a laser of 100 megawatts. One can *assume* that the problem of mirror accuracy can be solved by segmenting the mirror and controlling it adaptively, and that the problem of increasing laser power will yield to development. Nevertheless, these are only assumptions, and the problems of transporting the laser and its fuel to GEO and paying for it will remain. At a laser yield of about 500 joules per gram of fuel, the fuel for a single such intercept (using 100 megawatts of light for 100 seconds) weighs 20 tons and would take some 3 shuttle launches at $90 million each, to place the fuel for a single intercept into GEO ($300 million).

If one could have a laser of 0.3 micron wavelength (ultraviolet) instead of 3 micron and a mirror 30 meters in diameter with adequate reflectivity at this wavelength, and with the required ten times better perfection of its figure, the fuel requirement would fall by a factor 100. Nevertheless, such vastly expensive systems on satellites are easily countered by space mines or other ASAT means. No less a defense proponent than Edward Teller has testified and indicated in many interviews that no defensive system can depend upon satellites because they are "costly to put up and cheap to shoot down."

Furthermore, the vulnerability of the booster itself can be greatly reduced by various means: by rotating it, thereby spreading the heat over a larger region; by concealing it in smoke; by interposing reflecting foils so as to hide the booster itself; by deceiving the laser as to its position; and even by launching dummy boosters without warheads or silos, to provoke the defense to attack substantially more "ICBMs" than really exist, thus driving up the cost of defense. The ultimate problem for satellite-based lasers, or any orbital defensive system, is vulnerability to space mines —small satellites based in orbit in peacetime, remaining always in lethal range of their quarry satellites and ready to explode on command.

Some (notably George Keyworth, Jr., the President's science advisor) have advocated reducing the cost of such a system by placing the lasers and their fuel supply on the ground, directing the beam upward through the atmosphere by adaptive optics to compensate not only for imperfections of the mirror but also for the turbulent optical properties of the atmosphere. Such a ground-based laser would illuminate a relay mirror in orbit, which would then send the beam to other "fighting mirrors" which would direct the beam first at one booster and then at another. These mirrors also would be of very substantial size and cost and also vulnerable to space mines. As an additional element of vulnerability, the ground-based lasers could be put out of action by cloud, dust or sabotage.

"The President's defensive technologies initiative is a spectacularly ambitious one. Quite simply, it will require a scientific, technical, military, and organizational undertaking that will dwarf anything ever before mounted by the human race. . . .

I believe that mutual assured destruction is a morally bankrupt philosophy that places Government in the untenable position of refusing to defend its citizenry. What the President has proposed is no less than a moral recovery in American strategic policy which would take us from the horror of MAD to the promise of mutual assured protection. It is a goal which deserves the fervent support of all who yearn for a world safe from nuclear weapons. Unless we are willing to accept the prospect of a nuclear Pearl Harbor from space, we must now join the President in a new national commitment to mutual assured protection."

—*Ken Kramer (R-Colorado)*

Statement before the Subcommittee on Research and Development, House Armed Services Committee, Nov. 10, 1983, advocating the People's Protection Act. The Act was co-sponsored by Representatives Montgomery (D-Mississippi), Whitehurst (R-Virginia), Badham (R-California), Skelton (D-Missouri), Corcoran (R-Illinois), Davis (R-Michigan), Daniel Crane (R-Illinois), Hunter (R-California), Dyson (D-Missouri), Hartnett (R-South Carolina) and Skeen (R-New Mexico).

The other type of damaging energy that can be projected at nearly the speed of light consists of particles given their energy by particle accelerators in space. Although charged particles can be accelerated with efficiencies above 50 percent, they are bent by the Earth's magnetic field. Conversion of the charged particles to neutral particles can also be done with reasonable efficiency, but the quality of the

beam is spoiled, and the angular spread introduced dilutes the fluence at the target. The negative hydrogen atom, however, is unique among charged particles and would present a considerably smaller angular spread. The problems of developing and deploying a particle-beam defense even against a non-reactive adversary are enormous, but the system is ultimately vulnerable to space mines or to other ASAT weapons.

NEW SINCE Garwin's article in the May 1981 *Bulletin* is the X-ray laser driven by a nuclear explosive.[3] This "recombination-pumped" laser produces a low-density plasma by absorbing the energy from a nuclear explosion in space, at some 100 centimeters from a set of metal wires pointing at a distant target. Almost all the energy from the fission or fusion process in a space explosion resides initially in the thermal energy of the bomb materials or in the radiation energy of its volume; this energy can be radiated as thermal X rays before the materials of the weapon can expand far enough to acquire a substantial fraction of the bomb energy as kinetic energy. The relatively "hard" X-ray photons from the bomb are to be absorbed in copper or zinc, expanding the wires which continue to absorb photons and lose electrons, which then recombine selectively to populate the upper levels of the ions. Since no mirrors are available at these X-ray wavelengths and fluences, the angular aperture of the X-ray beam is at least as big as the angular aperture of one of the lasing rods—roughly the ratio of width to length—which in the example is about 1,000 microradians.

There are many problems in making a laser and many further problems in making an effective weapon from that laser. One might hope to achieve a transformation of 0.1 percent of the bomb energy into directed X rays, and if one uses the one milliradian angular aperture, this corresponds to a fluence from GEO of 0.1 percent of the bomb energy (which might be 20 kilotons) over a diameter on the order of 40 kilometers, or 0.01 joules per square centimeter which would not damage missiles or even satellites. The mechanism of damage by a short pulse of soft X rays consists of the blowoff of the thin surface layer absorbing the X rays, creating a shockwave going through the skin of the missile and an impulse communicated to the skin.[4] Because the laser X rays in the example are so soft, they are absorbed in a very thin layer of the order of 0.1 milligram per square centimeter and the resulting impulse is substantially less than that communicated by a similar fluence of hard X rays.

The particle beams and soft X-ray lasers can be negated by the same hardened, fast-burn boosters which cause so much trouble for a chemical laser system. Burning out below 80 kilometers, the booster is shielded by sufficient air to absorb the X-ray laser beam kilometers from the booster and to strip any hydrogen atom beam, allowing the resulting protons to be swept off target by the Earth's magnetic field.

Options

The preceding technical sketch suggests the vast range of choices available for attack on fragile satellites and the much greater difficulty associated with a defense which would "render nuclear weapons impotent." But as ASAT weapons, lasers and particle beams seem to offer only increased delay and higher cost, in comparison with space mines for which present technology would suffice.

The 1972 ABM Treaty already bans the development or testing (and even more the deployment) of ABM systems that are mobile, space-based or air-based, and President Reagan has stated that the United States would explore defensive possibilities within the constraints of that Treaty. Furthermore, many of the capabilities conferred by the adversary's satellites can be negated by means other than ASAT weapons—jamming, attack on ground stations, concealment and the like. Calamitous effects of attack on one's own satellites can be avoided by prudent planning, replacement capabilities, backup systems, and so forth.

Can one prove with certainty that space weapons will lead to disaster rather than to improved security or that global defense against ballistic missiles is *impossible*? If not, how do we dare deny ourselves these options? Are we joining the ranks of those who denied the possibility of airplane flight or of an ICBM bearing a nuclear warhead?

Over the years we have considered three possibilities concerning space weapons:

- no additional arms control measures in space;
- banning all military activities in space; and
- banning weapons in space.

In our opinion, the combination of a program for nullifying nuclear weapons by space means and the necessity for satellite components of any such system is a most severe threat to U.S. national security. That combination can convert the present world (with the universally acknowledged ability to destroy the Soviet Union, the United States, their allies and perhaps much of human life in the Northern Hemisphere) from a stable confrontation to an inherently unstable one, needing only the smallest spark to bring on a nuclear conflagration. This instability can arise from appearances—it does not need real capability. Pointing a toy handgun at a police officer is as good a way to be shot by the officer's partner as pointing a real gun. A supposedly effective ABM system depending on space elements could be countered by space mines within lethal range of the satellites. An attempt to prevent such vulnerability could be enforced in the early stages of deployment only by the destruction of the other side's missiles while it was launching space mines.

Banning all *military* activity from space seems neither necessary or desirable, since "military" applies to communication, navigation, administration, supply and other normal functions when performed for military personnel. The matter has also been discussed in the U.N. Committee on Disarmament, and even to that body a total ban on military activities seems neither practical nor desirable. Uninhibited ASAT development, in a protracted drive for space-supported defense (ICBM-killers), appears likely to lead to instability and attack even in peacetime.

During the U.S.-Soviet ASAT negotiations of 1978–1979, many options were considered, including the possession by

each side of a single type of ASAT system, the provision of sanctuary to satellites above a certain altitude, a total ban on damage to or destruction of satellites and the like. The negotiations were not resumed after the Soviet invasion of Afghanistan, but in 1981 the Soviet Union introduced into the United Nations a draft "treaty on the prohibition of the stationing of weapons of any kind in outer space." Unfortunately, that treaty appeared to convey protection only to those "space objects . . . placed in orbit in strict accordance with . . . this treaty" and to sanction the use of force against other satellites. Furthermore, the 1981 Soviet draft covered only space-based systems, thus permitting current Soviet and U.S. ASATs.

In September 1982, at a Senate Foreign Relations Committee hearing on the militarization of space, Richard Garwin testified that the 1981 Soviet draft should not be ignored and that if the U.S. government did not reply with a draft which would serve U.S. purposes, then even a private group might forward the cause of U.S. security by doing so. In May 1983 Admiral Noel Gayler, Kurt Gottfried and Garwin testified to the same committee in support of "A Treaty Limiting Antisatellite Weapons," which we had helped prepare, with the support of the Union of Concerned Scientists (see page 10S). The Soviet Union followed in August by introducing into the United Nations a new draft treaty "On the Prohibition of the Use of Force in Outer Space and from Outer Space with Regard to Earth" (see page 11S). Aside from what seems to be a totally unnecessary and unacceptable provision "not to test, nor use, for military, including counter-satellite ends, any manned spaceships," this 1983 Soviet draft provides a very suitable basis for early agreement.

Recommendations

The greatest urgency is to negotiate quickly a ban on weapons in space, starting with the Soviet draft of 1983, because it is presumably largely acceptable to the Soviet Union. Although it might be argued that in principle a better agreement could be obtained by going into more detail and taking longer to analyze and to negotiate, the situation is not static and the benefits of an early, all-encompassing agreement far outweigh any advantages which might follow from more detailed consideration.

The United States of course should take unilateral steps to make its military capabilities effective and robust against violation of such an agreement. This means, for example, backup communication and navigation systems for theater war. The United States should also (and the Soviet Union probably will) develop means for reducing the effectiveness of opposing satellite-based systems for support of conventional or nuclear military operations, short of putting weapons into space or damaging or destroying satellites. These measures could include jamming of communication links, decoys to deceive radar satellites and preparations for attack on ground stations not as safeguards necessitated by an ASAT ban, but as prudent self-interest.

An ASAT ban like that of our May 1983 draft or the Soviet draft of August 1983 cannot be expected to protect satellites in an all-out nuclear war. Nor can one realistically (or verifiably) eliminate residual threats to satellites, such as the nuclear-armed Soviet ABM system deployed at Moscow since before 1972 and permitted by the 1972 ABM Treaty. It would not eliminate the possibility of satellite destruction by a nuclear-armed ICBM launched to attack a "point-in-space" rather than a ground target. On the other hand, all the United States would renounce under an ASAT ban would be attack on Soviet satellites (and those of other countries) and some other roles for space weapons in war, (for example, attack on high-flying aircraft) which could better be performed by sensors in space and weapons launched from air or ground.

Regarding the denial of space for emplacing weapons for global defense, the proposed agreement would simply reinforce the constraints of the ABM Treaty, which President Reagan said the United States would observe in any case. We could and should continue to do theoretical and laboratory research on potential defensive systems, and a five-year review provision of a treaty of indefinite duration (as in the case of the ABM Treaty) would provide the opportunity to adapt the Treaty to technical and political realities and opportunities as they arise. □

Glossary of technical terms

geosynchronous orbit (GEO)—orbit in which a satellite remains stationary over a given area on Earth
hard X ray—one having short wavelength and high penetrating power
joule—unit of work or energy equivalent to 10^7 ergs or about 0.7375 foot-pounds or 0.2390 gram calories
kilo-—1,000
low-earth orbit (LEO)—orbit 100 to 500 kilometers in height
micro-—one-millionth
micron—one-millionth of a meter or one-thousandth of a millimeter
optical guidance system—active: emits energy which is reflected from an object; this reflected energy is then used for targeting; passive: senses energy from an object for targeting
plasma—ionized gas containing about equal numbers of positive ions and negative electrons. Differs from ordinary gas in being a good conductor of electricity and being affected by a magnetic field
radian—angular measurement equal to the angle at the center of a circle subtended by an arc equal in length to the radius of the circle; about 57.29 degrees
soft X ray—one having comparatively long wavelength and poor penetrating power
watt—power which produces energy at the rate of one joule per second; 1/746 horsepower

1. Richard L. Garwin, "Are We on the Verge of an Arms Race in Space?" *Bulletin* (May 1981), pp. 48–53.
2. A.B. Carter and D.N. Schwartz, eds., *Ballistic Missile Defense* (Washington, D.C.: The Brookings Institution, 1984).
3. Since there appear to be no recent unclassified technical articles by U.S. workers in this field available, we use results of Soviet research. F.V. Bunkin, V.I. Derzhiev and S.I. Yakovlenko, "Specification for Pumping X-Ray Laser with Ionizing Radiation," *Soviet Journal of Quantum Electronics* (July 1981), pp. 971–72.
4. Hans A. Bethe and Richard L. Garwin, "Anti-Ballistic Missile Systems," *Scientific American*, 218 (March 1968), pp. 21–31.

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A treaty limiting anti-satellite weapons

Draft treaty presented to the U.S. Senate Foreign Relations Committee in May 1983 by the Union of Concerned Scientists et al.

Article I

Each Party undertakes not to destroy, damage, render inoperable or change the flight trajectory of space objects of other States.

Article II

1. Each Party undertakes not to place in orbit around the Earth weapons for destroying, damaging, rendering inoperable, or changing the flight trajectory of space objects, or for damaging objects in the atmosphere or on the ground.

2. Each Party undertakes not to install such weapons on celestial bodies, or station such weapons in outer space in any other manner.

3. Each Party undertakes not to test such weapons in space or against space objects.

Article III

1. For the purpose of providing assurance of compliance with the provisions of this treaty, each Party shall use national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.

2. Verification by national technical means shall be supplemented, as appropriate, by such cooperative measures for contributing to the effectiveness of verification by national technical means as the Parties shall agree upon in the Standing Consultative Commission.

3. Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this Article.

4. Each Party undertakes not to use deliberate concealment measures which impede verification by national technical means of compliance with this treaty.

Article IV

1. To promote the objectives and implementation of the provisions of this treaty, the Parties shall use the Standing Consultative Commission, established by the Memorandum of Understanding Between the Government of the United States of America and the Government of the Union of Soviet Socialist Republics regarding the Establishment of a Standing Consultative Commission of December 21, 1972.

2. Within the framework of the Standing Consultative Commission, with respect to this treaty, the Parties will:

a) consider questions concerning compliance with the obligations assumed and related situations which may be considered ambiguous;

b) provide on a voluntary basis such information as either Party considers necessary to assure confidence in compliance with the obligations assumed;

c) consider questions involving unintended interference with national technical means of verification, and questions involving unintended impeding of verification by national technical means of compliance with the provisions of this treaty;

d) consider, as appropriate, cooperative measures contributing to the effectiveness of verification by national technical means;

e) consider possible changes in the strategic situation which have a bearing on the provisions of this treaty, including the activities of other States;

f) consider, as appropriate, possible proposals for further increasing the viability of this treaty, including proposals for amendments in accordance with the provisions of this treaty.

Article V

The Parties undertake to begin, promptly after the entry into force of this treaty, active negotiations with the objective of achieving, as soon as possible, agreement on further measures for the limitation and reduction of weapons subject to limitation in Article II of this treaty.

Article VI

In order to ensure the viability and effectiveness of this treaty, each Party undertakes not to circumvent the provisions of this treaty, through any other State or States, in any other manner.

Article VII

Each party undertakes not to assume any international obligation which would conflict with this treaty.

Article VIII

1. Each Party may propose amendments to this treaty.

2. Agreed amendments shall enter into force in accordance with the procedures governing the entry into force of this treaty.

Article IX

This treaty shall be of unlimited duration.

Article X

Each Party shall, in exercising its national sovereignty, have the right to withdraw from this treaty if it decides that extraordinary events related to the subject matter of this treaty have jeopardized its supreme interests. It shall give notice of its decisions to the other Party six months prior to withdrawal from the treaty. Such notice shall include a statement of the extraordinary events the notifying Party regards as having jeopardized its supreme interests.

Article XI

1. This treaty shall be subject to ratification in accordance with the constitutional procedures of each Party.

2. This treaty shall enter into force on the day of the exchange of instruments of ratification.

Article XII

1. Done in two copies, each in the English and Russian languages, both texts being equally authentic.

2. This treaty shall be registered pursuant to Article 102 of the Charter of the United Nations.

Treaty on the prohibition of the use of force in outer space and from space against the Earth

Presented by the Soviet Union to the General Assembly of the United Nations in August 1983

Article 1

It is prohibited to resort to the use or threat of force in outer space and the atmosphere and on the Earth through the utilization, as instruments of destruction, of space objects in orbit around the Earth, on celestial bodies or stationed in space in any other manner.

It is further prohibited to resort to the use or threat of force against space objects in orbit around the Earth, on celestial bodies or stationed in outer space in any other manner.

Article 2

In accordance with the provisions of article 1, States Parties to this treaty undertake:

1. Not to test or deploy by placing in orbit around the Earth or stationing on celestial bodies or in any other manner any space-based weapons for the destruction of objects on the Earth, in the atmosphere or in outer space.
2. Not to utilize space objects in orbit around the Earth, on celestial bodies or stationed in outer space in any other manner as means to destroy any targets on the Earth, in the atmosphere or in outer space.
3. Not to destroy, damage, disturb the normal functioning or change the flight trajectory of space objects of other States.
4. Not to test or create new anti-satellite systems and to destroy any anti-satellite systems that they may already have.
5. Not to test or use manned spacecraft for military, including anti-satellite, purposes.

Article 3

The States Parties to this treaty agree not to assist, encourage or induce any State, group of States, international organization or natural or legal person to engage in activities prohibited by this treaty.

Article 4

1. For the purpose of providing assurance of compliance with the provisions of this treaty, each State Party shall use the national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.
2. Each State Party undertakes not to interfere with the national technical means of verification of other States Parties operating in accordance with paragraph 1 of this article.

Article 5

1. The States Parties to this treaty undertake to consult and co-operate with each other in solving any problems that may arise in connection with the objectives of the treaty or its implementation.
2. Consultations and co-operation as provided in paragraph 1 of this article may also be undertaken by having recourse to appropriate international procedures within the United Nations and in accordance with its Charter. Such recourse may include utilization of the services of the Consultative Committee of States Parties to the treaty.
3. The Consultative Committee of States Parties to the treaty shall be convened by the depositary within one month after the receipt of a request from any State Party to this treaty. Any State may nominate a representative to serve on the Committee.

Article 6

Each State Party to this treaty undertakes to adopt such internal measures as it may deem necessary to fulfill its constitutional requirements in order to prohibit or prevent the carrying out of any activity contrary to the provisions of this treaty in any place whatever under its jurisdiction or control.

Article 7

Nothing in this treaty shall affect the rights and obligations of States under the Charter of the United Nations.

Article 8

Any dispute which may arise in connection with the implementation of this treaty shall be settled exclusively by peaceful means through recourse to the procedures provided for in the Charter of the United Nations.

Article 9

This treaty shall be of unlimited duration.

Article 10

1. This treaty shall be open to all States for signature at United Nations Headquarters in New York. Any State which does not sign this treaty before its entry into force in accordance with paragraph 3 of this article may accede to it at any time.
2. This treaty shall be subject to ratification by signatory States. Instruments of ratification and accession shall be deposited with the Secretary-General of the United Nations.
3. This treaty shall enter into force between the States which have deposited instruments of ratification upon the deposit with the Secretary-General of the United Nations of the fifth instrument of ratification, provided that such instruments have been deposited by the Union of Soviet Socialist Republics and the United States of America.
4. For States whose instruments of ratification or accession are deposited after the entry into force of this treaty, it shall enter into force on the date of the deposit of their instruments of ratification or accession.
5. The Secretary-General of the United Nations shall promptly inform all signatory and acceding States of the date of each signature, the date of deposit of each instrument of ratification or accession, the date of entry into force of this treaty as well as other notices.

Article 11

This treaty, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations, who shall send duly certified copies thereof to the Governments of the signatory and acceding States.

Effect on strategic stability

by Yevgeny P. Velikhov

TWO DISTINCT DIRECTIONS in space militarization have recently emerged—the creation of anti-satellite weapons (ASAT) and the development of space-based anti-missile systems (SBAMS). These two directions, I believe, are closely meshed with the problems of strategic balance and stability, and with prospects for substantial nuclear arms reductions.

With regard to anti-satellite weapons my impression is that their proponents in the United States have not adequately considered the real functions such weapons could have in the overall strategic context.

American scientists have explained to my colleagues and me that the advocates of U.S. anti-satellite systems push their plans through only because the Soviet Union is rapidly developing such systems. But the Soviet leadership has authoritatively and concretely declared that it unilaterally assumes the obligation not to test and deploy anti-satellite systems, and that it proposes to reach an agreement with all countries not to acquire new anti-satellite systems and to eliminate all the existing systems. Thus, the argument used by supporters of the U.S. ASAT system becomes completely groundless and unpersuasive.

As for the strategic consequences of the deployment of these weapons, if they were used, the side attacked would have to consider the hypothetical massive use of offensive nuclear weapons that could follow.

An attempt to destroy the opponent's satellites or even to "blind" them for some period of time can be justifiably regarded as the first step in initiating unlimited nuclear war. Destruction of the satellites would give every reason to the attacked side to retaliate immediately, destroying all possible enemy targets, without waiting for a nuclear attack on their own, launching complexes and other military and civil targets.

The creation of a constant threat to satellites through the deployment of an anti-satellite system will impair the prospects of reaching agreements on a freeze of nuclear weapons, deep reductions, and confidence in their verification. Even without this threat the verification problem is used in the United States as an argument to frustrate existing agreements.

Research by the Committee of Soviet Scientists on the problem of a freeze is nearing completion. But preliminary results show that existing national technical means of verification, based on the use of appropriate equipment on satellites, are good enough to verify agreements on the freeze of a wide range of weapon systems at various stages of development. In this connection I should emphasize that we must strengthen and not undermine confidence in national technical means. Invulnerability of satellites used for verification purposes is an important stabilizing politico-psychological factor and an indispensable technical part of a freeze agreement as well as of START and other negotiations.

In light of the decision by the U.S. side to reject a ban on ASAT weapons, we have the full right to doubt the seriousness of U.S. intentions to reach an agreement at the START talks.

It should be added that any hope of getting significant unilateral advantage from a strategic or political-military point of view is absolutely groundless. There are those who have great expectations for the technical sophistication of the U.S. anti-satellite system. In my view, however, judging by the record of the postwar decades, the United States has no chance of creating a tangible breakthrough in qualitative weapon-systems characteristics which would leave the Soviet Union far behind. And even if one side achieves short-term qualitative advantages, the other side can compensate by greater quantity.

RESEARCH AND development of space-based anti-missile systems as basic elements of widescale strategic "defense" have had a very powerful political and monetary impetus. But to my mind, those who insist on this kind of system with its attendant huge expenditures—claiming that it is the way to eliminate the threat of nuclear war to the United States and the whole world—do not see the whole complex of scientific and technological problems and possible consequences affecting strategic stability and international security.

A special research project on this problem was recently completed by the Committee of Soviet Scientists' Working Group headed by R. Sagdeev and A. Kokoshin.[4] The study gave particular attention to the potential weapon systems that could be created on the principle of directed energy transfer—weapon systems which are the subject of active debate in the United States today. Several types of energy sources at different stages of technical development were considered as possible components for a directed energy weapons system—lasers working in infrared, visible or ultraviolet range; X-ray lasers pumped by nuclear explosion; high-energy particle accelerators; UHF (ultra-high frequency) or microwave generators.

According to published information the hydrogen-fluoride infrared lasers seem to be at the most advanced stages of technical development in the United States. It is assumed that the prototype space-based anti-missile systems would include a five-megawatt laser and four-meter diameter mirror. Such a system could presumably be developed within

Yevgeny P. Velikhov, a vice-president of the Soviet Academy of Sciences and deputy director of the Kurchatov Institute of Atomic Energy in Moscow, is also chairman of the Committee of Soviet Scientists for Peace Against Nuclear War.

eight to ten years. According to the estimates by the Sagdeev-Kokoshin group, a space-based anti-missile system having approximately 18 orbital stations would be capable of destroying only about 15 ICBMs in 100 seconds (assuming massive launch), or up to 100 ICBMs in 15 minutes (assuming time-scattered launch). It is assumed that the launch sites would be within the range of two orbital stations simultaneously. A technically feasible improvement—some 10 to 20 kilojoules per square centimeter—of resistance to laser energy would make such a system incapable of destroying ICBMs.

The Working Group's estimates indicate further that development of a SBAMS effective enough to destroy 1,000 ICBMs in 100 seconds would require an increase in mirror diameter from four to 15 meters; in laser power capacity from five to 60 megawatts; and in fuel capacity from 45 to about 700 or 800 metric tons. Obviously, development of systems with these capabilities is currently beyond existing technical possibilities; considerably more intense research and development, on a wider scale, would be needed.

Still another requirement would be the development of a new heavy space launcher, much larger than the current space shuttle. Three to four times greater laser power capacity and two to three times larger mirror diameter would also be required if ICBM resistance to laser beams were further improved.

According to Western sources the development of neutral particle-beam accelerators which could be used in space-based anti-missile systems is not as advanced as the development of high-power lasers, and their construction would take considerable technical effort. The same situation obtains for the UHF generator-based system. Serious technical criticism could also apply to the possible uses of X-ray lasers.

The estimates mentioned above for large-scale space-based anti-missile systems using chemical lasers—up to 60 megawatts in power and with 15-meter mirror diameter—are related to a hypothetical "ideal" full-scale system, supposedly 100 percent reliable both technically and operationally. Obviously real SBAMS would not be absolutely reliable and would need backup duplicating components. The orbital stations themselves might have to be duplicated to compensate for technical unreliability. Operational unreliability would require the development of multi-layer SBAMS (having, in particular, traditional anti-missiles based on land or in space as an additional component). This has been under active consideration in the United States in recent years.

Even high operational reliability cannot guarantee absolute protection. For instance, a three-layer system, with 90 percent operational reliability for every layer, if used against 1,000 ICBMs with, say, 10 warheads each, would be expected to let through some 10 warheads. These could inflict tremendous damage.

Construction of effective SBAMS might require deployment of about 50 such platforms into polar orbits. Deploying fewer systems, in geosynchronous orbit, would take a bigger investment because of higher costs associated with such orbits, additional requirements in laser power, focusing, accuracy and so on.

The total cost of such systems, according to the Sagdeev-Kokoshin Working Group, would roughly amount to $400 billion. But that would be just one layer, which, as we have seen, would not be sufficient due to the need for redundancy.

THERE ARE SOUND reasons to believe that effective countermeasures could be taken more easily. According to the Group, such countermeasures would also be considerably cheaper—their cost amounting only to one or two percent of the total investment required for building a full-scale space-based anti-missile system. This cost ratio would probably also be preserved for the higher power capacity levels of the system and a consequent anti-system.

At a particular time, the side preparing a first strike can easily create a wide "window" among the battle platforms orbiting the Earth and use it for massive ICBM or SLBM attack. Thus the vulnerability of the system to counter-measures is the main factor leading to the view that such a system is intended for assuring a successful first strike. A strike could be launched against both offensive forces and anti-space ballistic missile defense systems of the other side, with the hope of reducing their ability to retaliate, while protecting itself with the space-based systems from such retaliation.

> "All attempts at gaining military superiority over the U.S.S.R. are futile. The Soviet Union will never allow them to succeed. It will never be caught defenseless by any threat.
>
> Let there be no mistake about this in Washington. It is time they stopped devising one option after another in search of the best ways of unleashing nuclear war in the hope of winning it. Engaging in this is not just irresponsible, it is insane."
>
> —*Yury Andropov*
>
> Replying to President Reagan's Star Wars speech in an interview in Pravda, March 27, 1983.

All this allows the conclusion that the deployment of even "ideal" systems would not assume (its proponents claim) a shift from the MAD (mutual assured destruction) posture—from the "strategy of deterrence based upon the threat of retaliation" to the defense-oriented strategy based on the ability to assure protection from a full-scale ICBM attack. On the contrary, the deployment of such a system would significantly complicate the maintenance of deterrence, making it highly unstable, for it would stimulate the illusion of advantages (damage limitation and even a chance for surviving nuclear war) associated with a first strike.

There are good reasons to believe that if both sides possessed space-based systems the destabilizing effect would be much greater than if such systems were available to only one side. In the context of strategic logic (without consider-

Figure 2. U.S. and Soviet satellites in orbit

Orbit	Mission	United States 1983	United States 1989	Soviet Union 1983	Soviet Union 1989
Low					
100–500 kilometers	Photo reconnaissance	4	2	2	2
	Radar surveillance	–	–	2	2
	Electronic intelligence	6	–	–	–
	Manned	1	1	1	2
	Subtotal	*11*	*3*	*5*	*6*
Medium					
500–3,000 kilometers	Communication military	–	–	29	2
	Navigation	5	–	10	–
	Electronic intelligence	6	14	10	8
	Weather military	2	2	3	3
	Weather civil	2	2	1	1
	Remote sensing civil	1	1	1	2
	Subtotal	*16*	*19*	*54*	*16*
Semi-synchronous					
400 x 40,000 kilometers	Early warning	–	–	9	–
	Communication military	2	2	4	4
	Communication civil	–	–	8	–
	Subtotal	*2*	*2*	*21*	*4*
Semi-synchronous					
20,000 x 20,000 kilometers	Navigation	6	21	2	12
Synchronous					
36,000 x 36,000 kilometers	Early warning	3	3	–	3
	Electronic intelligence	4	4	–	–
	Communication military	20*	22*	–	12
	Communication civil	30**	65**	10	13
	Weather	2	2	–	1
	Subtotal	*59*	*96*	*10*	*29*
Total		**94**	**141**	**90**	**67**

*Includes NATO satellites
**Includes INTELSAT satellites

Source: John Pike, "Anti-satellite weapons," *Federation of American Scientists Public Interest Report* (Nov. 1983), p. 3. Reprinted with permission of the author.

ing psychological and political aspects) this thinking arises from the fact that if both sides had these systems their impetus for a preemptive first strike would be greater, since each side could hope to secure an advantage by striking first.

As the Committee of Soviet Scientists noted, the U.S. refusal to undertake a no-first-use obligation and U.S. strategic programs aimed at acquiring a first-strike potential are additional reasons for considering prospective U.S. space-based systems as part of a first-strike strategy. An important element in implementing this policy is the deployment of U.S. medium-range missiles (particularly Pershing II) in Western Europe, aimed at "decapitation."

In contrast, the Soviet side, bearing in mind the tremendous importance of strengthening strategic stability in the atmosphere of growing political-military tensions, in June 1982 undertook the unilateral obligation not to use nuclear weapons first. This position was afterwards confirmed more than once by the highest Soviet government and military leaders. This obligation is not only political and diplomatic in character; it has become an integral part of Soviet military training and entails additional scientific and technological decisions.

In line with this commitment much more attention is paid to the goal of preventing non-nuclear conflict from growing into nuclear. Thus, more rigid limits have been set for troop training and command, and stricter controls organized to make unauthorized launch of tactical or strategic nuclear weapons impossible.

Besides the likelihood of countermeasures to space-based anti-missile systems—for example, hardening of ICBM boosters—the Sagdeev-Kokoshin Working Group thinks it highly probable that there will emerge a weapon intended to neutralize these systems (counter- "anti-SBAMS"). I agree with those specialists who have concluded that during the development and deployment stages of SBAMS, penetration capabilities of strategic offensive forces, including their qualitative improvement, will be modernized more rapidly.

The development of SBAMS could stimulate an increase in the arsenals of strategic delivery vehicles and nuclear warheads, for example, strategic cruise missiles, including sea- and ground-launched cruise missiles. Cruise missile deployment is extremely difficult if not impossible to verify by national technical means, and U.S. experts who suppose that the United States can retain a monopoly on strategic cruise missiles are badly misled.

If tests of the space-based systems were to begin, to say nothing of their actual deployment, the permanent ABM Treaty signed on May 26, 1972, would be threatened. Item 1, Article V of this Treaty postulates: "Each Party undertakes not to develop, test or deploy ABM systems or components which are sea-based, air-based, space-based or mobile land-based."

It is hard to overestimate the importance of this U.S.-Soviet Treaty today for it remains the only ratified and acting agreement in the area of strategic arms limitation.

THE PRESENCE of tested and deployed elements of space-based systems, even of limited scope, could considerably hinder the progress of negotiations on strategic arms limitations and limitations of nuclear weapons in general.

Such an unfortunate result would be inevitable. The introduction of a qualitatively new component in the strategic arsenal of one or both sides would confuse the existing assessments of strategic balances and bring up additional complications in the comparison of forces. The development of space-based anti-missile systems is likely to go in different ways in the two countries as has been true of the strategic arms race. Such differences would increase the asymmetries in the strategic potentials of our two countries—thus making comparisons even more difficult. These asymmetries could become increasingly significant in the face of deployment of potential anti-SBAMS systems and countersystems.

After these systems were deployed, U.S.-Soviet strategic arms limitation and reduction agreements would be more complex and correspondingly more difficult to understand on the part of the public, which plays an increasingly important role in solving the problems of war and peace.

With regard to international political consequences the deployment of space-based systems cannot be ignored. They would inevitably become a serious obstacle for U.S.-Soviet cooperation in the peaceful uses of space. Yet the potential value of such cooperation is important from economic, scientific and technological points of view, because of the many mutually complementary characteristics of the Soviet and U.S. space programs. Cooperation in this area could be a very positive factor, politically and psychologically, in improving U.S.-Soviet relations in general, and in strengthening the confidence between the peoples and the leaders of the two great powers.

THE POTENTIAL impact of a large-scale space-based anti-missile program on the strategic balance would be to substantially increase both the risk of a preemptive strike and the likelihood of wrong and fatal decisions in crises. Hence even if rough parity in strategic forces were preserved, strategic stability would be seriously undermined.

Deployment of strategic "defensive systems" would definitely trigger a chain reaction in the development of new weapon systems. That would confuse the strategic balance to an unprecedented degree and increase the uncertainty in political-military decision-making.

In view of the existing dialectical relationship between strategic offensive and defensive systems, even the possibility of building SBAMS would seriously undermine the possibility of future U.S.-Soviet (and perhaps multilateral) agreements on strategic arms limitation and reduction talks, and thus the prospects for strengthening strategic stability.

Abrogation of the ABM Treaty would in turn undoubtedly lessen chances for reaching mutually beneficial strategic arms limitation and reduction agreements in the near future. The stabilizing regime created by the 1972 ABM Treaty could be strengthened significantly by agreements on the non-deployment in space of any weapons and the non-use of force in space. These would include a ban on the use of force from space against the Earth, as well as a ban on anti-satellite weapons.

Vast resources would be required for construction of a space-based anti-missile system, to say nothing of the scientific and technological capital already devoted to this enterprise. These funds and efforts could be effectively diverted to large-scale international bilateral and national programs of a peaceful nature. If this were to happen, that part of U.S. industry which would have been employed to develop the space system could effectively be engaged in such peaceful projects.

It was the unanimous view of the Committee of Soviet Scientists that programs of cooperation in this field could substantially contribute to and expedite the solution of increasingly acute global problems such as economic development, energy, resources and ecology. They could also create a basis for successful space exploration by future generations of the Earth's inhabitants. □

**Political-Military Implications of Prospective American Space-Based Anti-Missile System*, report issued by the Committee of Soviet Scientists for Peace Against the Nuclear Threat (Moscow: 1983).

R. Sagdeev heads the Institute of Space Research of the Soviet Academy of Sciences. He serves as vice-chairman of the Committee of Soviet Scientists. A. Kokoshin is head of the political-military department in the Institute of U.S. and Canadian Studies of the Soviet Academy of Sciences and is vice-chairman of the Committee of Soviet Scientists. The Working Group included members of the Institutes of Space Research, of World Economy and International Relations, and of U.S. and Canadian Studies: A. Arbatov, A. Vasiliev, R. Nazirov, O. Prilutsky, R. Rodin and S. Rodionov.

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Averting a Brobdingnagian Skeet Shoot

Arms Control Measures for Anti-Satellite Weapons

Donald L. Hafner

. . . Imagination can figure nothing so grand, so surprising, and so astonishing. It looked as if ten thousand flashes of lightning were darting at the same time from every corner of the sky. . .

—Gulliver's Travels, *A Voyage To Brobdingnag*

On June 8, 1978, American and Soviet negotiators seated themselves at the bargaining table in Helsinki and convened the first round of talks on arms control measures for anti-satellite (ASAT) weapons. On December 24, 1979, while preparations were underway for a fourth round of ASAT talks, the Soviets invaded Afghanistan, making it impossible to continue "business as usual" on arms control with the Soviet Union.

No one would counsel the resumption of ASAT negotiations if it were contrary to U.S. interests in light of recent Soviet behavior. However, the problems which brought the United States to the negotiating table in the first place have not disappeared. They promise only to get worse. The United States therefore still has a compelling reason for exploring effective and verifiable arms control measures for space weapons: at a time when satellites are becoming progressively vital to our national security, we do not have any other means for reliably protecting our satellites against future ASAT weaponry.

The opportunity that the United States now has before it to place constraints upon arms competition in the broad reaches of outer space is ripe but perishable. The ASAT technologies currently available to the United States and the Soviet Union are crude but suggestive. Should the momentum of ASAT programs increase, it is evident that the two sides will provoke each other into expending billions of dollars, all in preparation for a "Brobdingnagian skeet shoot"[1] from which neither side is likely to derive a net advan-

1. This colorful image, recalling the land of giants in *Gulliver's Travels*, was offered by Paul Warnke, chief U.S. negotiator at the first round of ASAT talks.

Donald L. Hafner is an Associate Professor of Political Science at Boston College. During 1977–78, while serving with the Arms Control and Disarmament Agency, Professor Hafner was an advisor to the SALT delegation in Geneva and an analyst with the NSC ASAT Working Group.

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tage in security. The ASAT negotiations themselves retarded this momentum, because the Soviets voluntarily suspended their ASAT testing program while the talks were in progress. But with the negotiations now in abeyance, the Soviets resumed testing on April 18, 1980, with the launch of Cosmos 1174. Moreover, a U.S. intelligence report in May asserted that there is "evidence of a Soviet project to develop a space-based laser weapon that we believe may have an anti-satellite application. . . . such weapons may be available for operational use in the mid- to the late 1980s." Clearly there is an urgency to exploring arms control prospects.

Since this novel area of arms control touches on issues not widely discussed in public, it is well to review the matters at stake and to suggest what an effective ASAT agreement should contain.

Anti-Satellite Weapons: Present and Future Technology

At an increasing rate, satellites are being exploited by the United States to perform a variety of civil and military tasks, including communication, meteorology, navigation, surveillance and reconnaissance, warning of military attack, and monitoring of arms control agreements. As reusable launch boosters such as the Space Shuttle reduce the cost of placing satellites in orbit and make sustained manned operations feasible, the list of tasks will expand.

At present, the United States and the Soviet Union together have about 150 active satellites in orbit.[2] By the mid-1980s that number will rise to around 200. The total investment represented by these satellites cannot be fixed, because neither side will acknowledge the precise number or cost of military and intelligence satellites. Only rough yardsticks are available. The U.S. Defense Department, for instance, is establishing a set of complex communications networks (FLTSATCOM, AFSATCOM, DSCS, etc.), with satellites incorporating costly protective features to guard against such threats as electronic jamming. Funding for development, procurement, and launching of these military systems has been $200–300 million annually for the past several years and will continue at these levels into the 1980s. It would not be surprising, therefore, if the satellites currently maintained in orbit by the United States or the Soviet Union represented $5–10 billion worth of investment—a figure that begins to rival the cost of major strategic weapons systems, such as Trident.

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2. The total number of no-longer-functioning satellites still in orbit is much greater, and the total number of objects in orbit, including debris, is larger still.

The value of satellites, however, is not properly weighed in terms of their investment costs alone. Our growing dependence upon satellites for carrying out a variety of vital missions is a more pertinent index of their importance—and in turn, of the importance of protecting them through arms control measures. This dependence varies from case to case. In many instances, the missions performed by satellites were previously carried out by earth-based facilities: in the communications area, for instance, by undersea cables and radio transmitters; in the navigation area, by such radio beacon systems as LORAN. Satellites are now preferred for these missions because they can perform with higher efficiencies. Many of the ground-based networks that they replaced have subsequently been dismantled. Nonetheless, satellites may not be indispensible for these tasks. If we fail to reach an ASAT agreement which protects satellites, the United States could presumably revert to ground-based systems, though this would mean higher costs, continued dependence upon overseas installations, and a U.S. military presence in foreign nations that might be difficult to ensure.

For certain other missions, however, satellites provide unique capabilities that cannot readily be duplicated by ground-based systems. Overhead photographic surveillance, so crucial for military intelligence and crisis monitoring during regional conflicts, is an important example. It would be feasible technically to carry out such missions by less exotic means than satellites—by U-2s for instance. But the political obstacles to securing broad consent among nations for such surveillance overflights are so overwhelming that, as a practical matter, satellites are indispensable. Hence, it is a matter of concern that satellites are quite vulnerable to an array of techniques for attacking them or interfering with their missions.

These vulnerabilities are a problem for virtually any satellite, not just those belonging to military or intelligence agencies. No attacker is going to grant free passage to a militarily useful communications or meteorology satellite, simply because it carries the emblem of a civilian agency or international corporation. An article in the Soviet press published on the eve of the first ASAT talks for instance, offered a well-informed discussion of the interchangeability of U.S. and NATO satellites for military communications purposes.[3] So the protection of a vast number and variety of satellites is at issue here.

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3. Col. A, Zhovanki, "Long-Range Communications: Problems and Solutions" *Krasnaya Zvezda*, June 7, 1978. Under the Defense Department's GAPFILLER program in the late 1970s, for example, the U.S. Navy met its Fleet Satellite Communications requirements by leasing channels on the civilian MARISAT satellites.

Until recently, the United States devoted relatively little effort to diminishing the vulnerability of its satellites. Since the costs of launching a complex satellite were typically above $20 million and rose as the weight of the satellite increased, it was penny-wise to cram every available ounce with equipment and to omit survivability features (such as armor plating, anti-jamming devices, evasive maneuvering capabilities, shielding against lasers, etc.). Some intrinsic "hardness" against attacks or interference occurred as an incidental benefit of general efforts to make satellites more durable in the hostile environment of space. But far more extensive and costly defensive measures would be necessary, if the Soviets incorporate the best technology into ASAT weapons—and even then the protection would be marginal at best.

As matters stand now, the best technology has not yet been applied to ASAT weapons. There is at the present time a breathing spell during which the future can still be shaped. This has not been due to a lack of imagination or foresight on the part of ASAT designers. Schemes for shooting down satellites predate satellites. The first study of ASAT systems commissioned by the U.S. Air Force was undertaken in the mid-1950s, before the Soviets had launched Sputnik. Even at that time, it was evident that a variety of techniques for attacking satellites were conceivable. And since ASAT weapons come in great variety, an ASAT arms control agreement must be couched in broad terms to encompass all possibilities.

The earliest U.S. studies of ASAT systems focused on two basic approaches: either a "killer satellite" interceptor that would be placed in orbit and then maneuvered to its target, or a direct-ascent interceptor that would rise from the earth and promptly intercept the target when it passed overhead. With either technique, the target could be destroyed by a nuclear warhead or by some non-nuclear means. A nuclear warhead would have a kill radius of tens or even hundreds of miles, depending upon the intrinsic hardness of the target to nuclear radiation. But the drawbacks are that the radiation would also damage friendly satellites at great distances from the enemy target, and by breaching the nuclear threshold, such a warhead could escalate a conventional confrontation to higher levels of violence. Non-nuclear warheads avoid these problems, but their kill radii are also smaller, and so they require more precise interceptor accuracy and timing in order to get the warhead close enough to the target to do damage.

"Killer satellite" interceptors were the earliest means devised for getting the accuracy needed with non-nuclear warheads. Launched so that it has an orbit and speed roughly comparable to the enemy target, a "co-orbital" interceptor can then make last-minute maneuvers while closing on the target

at relatively low speeds. The interceptor must guide itself during the last moments of attack, so it requires a homing system, e.g., an active search radar or optical scanner. (Guidance from the ground would be insufficiently precise or timely for the last phase of engagement.) If the maneuvering capability of the interceptor can be made great enough, and if the detection range of the homing device is greatly extended, then the relatively low closing speeds provided by a co-orbital approach would not be necessary at all. The interceptor could instead be boosted in direct-ascent from its ground site to detect, pursue, and destroy a target passing overhead. Such a system could be highly effective against satellites in lower orbits (that is, those below about 1,000–2,000 nautical miles), because its swift approach would give the target little warning or time for evasive measures. In the past, however, technology has not been available to meet these more rigorous maneuvering or homing requirements for non-nuclear interceptors. Schemes for direct-ascent systems relied instead upon nuclear warheads that did not require great accuracy, but which had the drawbacks noted above.

The first U.S. Air Force anti-satellite program (SAINT) was a co-orbital interceptor that was to inspect and destroy targets. The project appears to have been a stalking horse for other Air Force space projects, rather than a fully-conceived ASAT effort. In any case, SAINT never advanced beyond the research and development phase and was cancelled in 1962. The U.S. ASAT mission then became an orphan, temporarily given shelter under the Army's ABM program by those who recognized that, in principle, the ABM test facilities on Kwajalein Island in the Pacific could also work reasonably well as a nuclear-armed direct-ascent ASAT system against low altitude satellites. In 1964, prodded by concerns over a Soviet orbital bombing threat (FOBS and MOBS), the Air Force resumed ASAT missions by establishing nuclear-armed Thor IRBMs on Johnston Island in the Pacific. The location was appropriate for intercepting Soviet satellites on their initial orbital passes, but the THORS were costly and clumsy instruments. The facility was closed down in the early 1970s.

The United States has now reverted to non-nuclear direct-ascent ASAT schemes, derived from ABM research. Contracts were awarded in 1977 to the Vought Corporation to develop a Miniature Homing Vehicle (MHV), weighing 34 pounds, to be launched from the ground or from an aircraft on a relatively inexpensive booster.[4] For FY 1980, the Defense Department

4. The favored scheme is an air-launch using a modified SRAM as booster; cost estimate for the booster alone, $1 million each.

budget request for R&D on this MHV system was $63 million. Since the MHV interceptor is designed to destroy its target by ramming it, very high accuracies (near-zero CEP against targets closing at speeds greater than 17,000 mph) will have to be achieved. Comparable marvels have been produced by American technology in the past, but there are knowledgeable critics whose doubts about the feasibility of the MHV will not be laid to rest until flight tests actually succeed against orbiting targets. The first space tests of the MHV will reportedly not occur until 1982. If the United States were instead to pursue a less exotic co-orbital interceptor, using off-the-shelf hardware, a rudimentary ASAT system could probably be demonstrated in short order. For the moment, however, the United States does not have a weapon system specifically dedicated to the ASAT mission, despite expenditures of several hundred million dollars on various schemes over the past twenty years.

The Soviets have undoubtedly also explored a variety of ASAT approaches. In 1964, a PKO division[5] of the Soviet PVO-Strany strategic defense forces was established, charged with the mission of "destroying the enemy's cosmic means of fighting." By 1967, preliminary tests of an ASAT system had begun. The system is based on a co-orbital interceptor that destroys its target with a non-nuclear warhead after first maneuvering to cross the path of the target. In the early 1970s, the Soviets ceased flight tests of the interceptor, and then resumed them in 1976, with roughly four interceptor launches per year. The moratorium undertaken during the ASAT negotiations produced another hiatus from May, 1978 to April, 1980. Substantial advances in weapons technology have occurred since the mid-1960s when the Soviet ASAT was designed, and an interceptor based on the older hardware would have inherently limited capabilities, reliability, and growth potential. Public accounts of the Soviet tests periodically given by the Defense Department, for instance, indicate that the interceptor has executed the steps necessary for target destruction in only about 50 percent of the tests. (Classified intelligence data on the Soviet program, of course, is much more precise and specific.)

This co-orbital interceptor assembled from the cumbersome technology of the 1960s requires a large launch booster comparable to the bigger Soviet ICBMs, and even with that it could only reach satellites in lower orbits.[6]

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5. *Protivo-Kozmicheskaya Oborona*: literally, "anti-cosmic defense."
6. TRW, the American aerospace firm, has published data estimating the weight of the Soviet ASAT interceptor at about 4,500 pounds, identifying the booster as a missile adapted from the

Intercepting targets at geosynchronous orbits (i.e., "stationary" satellites at altitudes of 22,300 nm) would require a booster comparable to the U.S. Saturn-B rocket that launched the 85 ton Skylab. An extensive ASAT system based on such boosters would not only be extremely costly, it also would not be a fast-reaction system, since launch preparations for such boosters can require weeks or months. The Soviet interceptor itself has limited fuel for maneuvering, and thus is largely restricted to attacking when the target is in an orbital pass that would carry it almost directly over (i.e., in-plane with) the ASAT launch site—something that happens only once every twelve hours for any particular satellite in lower orbits.

Nonetheless, against satellites lacking defensive countermeasures, the demonstrated Soviet ASAT system could be, as Defense Secretary Brown has remarked, "somewhat troublesome." The lower orbits reachable with the Soviet ASAT are the ones used by the United States for many of its photo-reconnaissance, electronic intelligence, meteorological, and navigation satellite networks. With limited Soviet ASAT maneuverability and reliability, it could take days to weeks for the Soviets to eliminate entire U.S. satellite networks; but surprise attacks on a handful of U.S. satellites would be within the capabilities of the current Soviet system.

These Soviet and American programs by no means exhaust the range of possible ASAT schemes. The missions of some satellites can be impeded, even without sending interceptors against them, by using various methods of interference such as electronic jamming. Many satellites, as part of their mission (e.g., communications or navigational assistance), must pick up very weak radio signals, amplify them, and relay them on to other stations. In addition, satellites may require periodic "housekeeping" instructions radioed from earth so that they remain in appropriate orbit and orientation. Under some circumstances, an adversary may be able to use powerful transmitters, such as early warning radars or large space-communication antennae, to jam or even burn out the sensitive receivers on satellites and thus block their use. Similarly, the Soviets now have satellites capable of scanning the oceans with radar and detecting the echoes reflected back from ships on the surface. (The Soviets' Cosmos 954, which scattered radioactive debris over northern Canada when it fell from orbit in September 1977, was a satellite of this

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Soviet SS-9 ICBM, and listing the launch dates and orbit configurations for Soviet targets and ASAT interceptors. The highest altitude listed for the interceptor in these tests was about 1,250 nm. See *TRW Space Log 1977*. The bulk of American non-geosynchronous satellites orbit the earth at altitudes of 100–20,000 nm.

type.) Such satellites are vulnerable not only to active jamming of the radar receiver, but also to a variety of passive countermeasures, such as decoy ships or "corner reflectors" that could confuse the radar by making small vessels appear as large ships.

The susceptibility of current satellites to such interference is difficult to estimate, because success with such techniques is highly dependent upon whether the attacker has good information about the satellite's electronics, whether he has jamming transmitters geographically distributed so they can overwhelm satellites at appropriate times, etc. These factors will vary from case to case, depending upon where, when, and in what form conflict occurs. But broadly speaking, these techniques are likely to be more disruptive to the tactical than to the strategic missions of satellites, and they are likely to be more successful against high altitude and geosynchronous satellites, rather than low orbit satellites.[7] An exception would be low orbit radar reconnaissance satellites, which appear to be particularly vulnerable to "spoofing." Interference must, therefore, be considered as part of the ASAT problem.

All this is rather prosaic ASAT weaponry. There is yet another whole class of potential ASAT weapons: directed-energy or "beam" weapons, such as lasers or charged-particle beams. By blinding, overheating, or even destroying fragile satellite components, such systems could work well as ASAT weapons. Among many specialists there is doubt that practical particle-beam weapons can even be built; fewer doubts exist about the feasibility of high-power laser weapons.

Ground-based laser weapons would have limited effectiveness against most satellites, even with power outputs in the megawatt range. Both cloud cover and the atmosphere rob laser beams of substantial power. The tendency of a laser beam to spread out over distance also complicates the task of bringing destructive energy to bear on distant satellites. Consequently, the threat from such weapons would be posed primarily to low orbit satellites. Airborne lasers would get above much of the atmosphere, but there are limits to the power output and lethal range of a laser that must be fitted into an airplane. A multi-megawatt orbiting laser weapon, on the other hand, could

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7. The technical reason for this is that jamming requires line-of-sight, or even main-lobe access to the satellite's antenna as well as in-band power delivery greater than that of the satellite's own users. These conditions are easier to meet in tactical situations, where the satellite's users are probably nearby and operating with low-power transmitters, or where the high orbit of the satellite exposes it to line-of-sight access by powerful jamming transmitters in a wide geographical area.

operate above the power-robbing effects of the atmosphere and would be capable of damaging targets hundreds of miles away in outer space. But there are daunting technological challenges (and uncertain cost) to be faced in generating and aiming the explosive force of a multi-megawatt space laser, and even Defense Department enthusiasts of such weapons concede that they would not be available to the United States before the mid-1990s. Nonetheless, the destructive potential and probable cost of such futuristic weapons are sobering enough to suggest what unbridled arms competition in outer space might entail.

The seductive attraction of ASAT weapons is that in the absence of arms control restraints, it appears that technology will favor the offense over the defense. Plating satellites with armor or other protective coatings might work as a defense against unsophisticated conventional warheads or ground-based lasers, but not against the more advanced possibilities. (An MHV interceptor, for instance, colliding at speeds over 17,000 mph could defeat the armor of a battle tank.) Giving satellites the capacity to maneuver out of harm's way when attacked, or the capacity to destroy oncoming attackers with their own defensive lasers are suggested defenses. But a satellite defense system would first have to detect oncoming ASAT weapons, using active radars or optical scanners, and thus it would be susceptible to a crafty attacker who could jam or confuse the sensors and exhaust maneuvering engines or defensive lasers. One could envision satellites of the future burdened with thousands of pounds of defensive measures, just to protect a few hundred pounds of vital equipment. An alternative scheme advocated by some in the Defense Department would involve "convoying" satellites under the protection of huge defensive laser satellites. But satellites with different missions could not readily be clustered together into "convoys" without severely compromising their missions. And in any case, the protecting satellite would itself be subject to the problems of jamming and exhaustion just mentioned.

The vitality of satellite defenses could be restored if a cap were placed on offensive ASAT weapons, and this is what ASAT arms control would do. Consider, for instance, that a promising defensive technique for satellites would be simply to multiply the total number of satellites, so that the attacker's prospects of destroying them all in time to have a decisive impact upon a conflict would be diminished. The U.S. Space Shuttle will make satellite systems much cheaper, by reducing launching costs and by permitting retrieval or repair of satellites, thus reducing the need for overly durable and redundant equipment on them. By duplicating and diversifying missions

among a greater number of cheaper satellites (and storing some duplicates in orbit in an apparently inert condition to disguise their missions or presence), the defense could present a formidable challenge to any would-be attacker. The effectiveness of this approach declines, however, if the attacker has plenty of cheap, reliable ASAT interceptors available. And this underscores the importance of exploring ASAT arms control measures promptly.

As yet, neither the United States nor the Soviet Union has tested or deployed such an efficient ASAT device. Nor is there any immediate prospect of a cheap interceptor capable of reaching the large number of high-altitude and geosynchronous satellites. Even the U.S. MHV device would require a Minuteman-class booster to carry it up to geosynchronous altitudes. Yet undoubtedly, if ASAT competition continues without restraint, such devices will be developed and deployed. It is in this sense that the United States faces a ripe but perishable opportunity to avert greater threats to its satellite systems.

The Path to Arms Control for ASATs

Despite the attractiveness of an arms control approach to ASAT threats, it was not given broad consideration within the U.S. government until recently. Instead, policy tended to vacillate between indifference to the threat and strictly offensive responses to it, that is, acquiring our own ASAT capability. The Soviet ASAT program is over a decade old, and there were several interagency study groups assembled within the U.S. government during those years to examine U.S. policy on ASAT systems. Repeatedly the judgment had been made that neither the Soviet ASAT capability nor the increased Soviet military use of space satellites warranted U.S. investment in an extensive ASAT system. In a period of tight military budgets, the emphasis had been upon using limited funds to improve U.S. exploitation of space, rather than on trying to threaten Soviet satellites.

The turning point came literally in the final days of the Ford Administration, when a National Security Council decision memorandum instructed the Defense Department to begin a new ASAT program. The precipitating event was the resumption of Soviet ASAT testing in 1976. Arguments were already being made within the State Department, urging the administration to seek an ASAT arms control agreement. Instead, Secretary of State Kissinger argued that the U.S. should redress any asymmetry in ASAT capabilities between the sides before any arms control restraints were considered. The

directive by the Ford Administration to go ahead with the MHV system did call for a study of arms control options, but it did not include any concrete proposal for inviting the Soviets to ASAT talks. Kissinger may have felt it was premature to make such a proposal; or indeed, he may not have favored negotiations at all.

The case made by the Defense Department for acquiring an ASAT system, however, had a number of defects. The initial argument was that the United States ought to match the Soviet ASAT capacity as a means of deterring attacks on U.S. satellites. Yet if the U.S. is indeed becoming more dependent upon satellites for its military effectiveness, then it is well to bear in mind that destroying Soviet satellites in a rage of retaliation will not restore our own satellite capabilities.

Deterrence has other shortcomings as well. It is not obvious that the mere threat of U.S. retaliation would deter the Soviets from attacking U.S. satellites, because Soviet dependence upon satellites is lower than American dependence. The Soviets have fewer military forces deployed beyond their homeland and thus can rely upon interior (ground-based) lines of communication. Their strategic forces have less need for worldwide communications or navigation aids, since their strategic bomber fleet is so small and their longer-range SLBM submarines can operate near home shores. The role of the Soviet Navy is sea interdiction rather than the more demanding task of sea control, and thus it may be less dependent upon global communications for coordination and control. For conflicts near the Soviet borders, ground-based surveillance and reconnaissance systems can fill gaps created by the loss of satellites. And lastly, Soviet military planning is aimed at short, intense warfare begun with surprise and massive shock. Here the emphasis would be upon commands and data distributed before the conflict begins, when the United States would be inhibited from preemptive attacks on Soviet satellites. (Passive concealment techniques for confusing Soviet radar reconnaissance or intelligence satellites, on the other hand, would not involve such inhibitions.)

In evaluating the efficacy of deterrence, the United States must make some judgments about where conflicts are most likely to occur. If, as seems likely, the vital conflicts would be on the Soviet periphery (in Europe, the Persian Gulf, the Middle East), then the Soviets might well be able to get along without their satellites—which means that a U.S. retaliatory threat would have doubtful deterrence value. The weakness of the deterrence argument was recently conceded by Seymour Zeiberg, deputy undersecretary of Defense R&D for space systems, who oversees the U.S. ASAT project:

The idea of tit-for-tat with satellites to my mind does not make sense because of the great asymmetry in the nature of [U.S. and Soviet] satellites, the deployment of satellites, etc. . . . For example, the Soviets have a very redundant communications system to thei forces. They have two of everything. So taking out a communications satellite is not going to extract much of a price from them. If they took out one of our communications satellites, it would be quite different.[8]

What the Defense Department now argues instead is that the United States needs an ASAT capability in order to initiate attacks on a relatively small number of Soviet satellites that pose a danger to U.S. forces. Of particular concern are the Soviet radar and electronic surveillance satellites that can scan the oceans for U.S. naval forces and provide targeting information for, say, long-range cruise missiles. Even if shooting these satellites down is the only way to cope with them (and that has not been demonstrated), the problem with this argument is that, as the price for having its own ASAT, the United States will also be exposing all of its own satellites to comparable Soviet ASAT threats. If deterrence cannot protect U.S. space systems in a world of ASATs, what then is the alternative?

The answer of the Ford Administration was a rapid surge in spending on "space defense systems," increased in the Defense Department budget from $61 million in FY 1977 to $126 million proposed for FY 1978, and $265 million projected for FY 1979. But these figures were quite misleading. A substantial chunk of the funding was for the MHV program; actual funding fell short of projections ($73.0 million in FY 1979, not $265 million); and only a small portion of the funding was actually devoted to the category of "satellite survivability" (only $19 million of the $73 million in FY 1979).[9] Even within this latter category were contained programs for devices, such as impact sensors, that would detect when a satellite had been attacked but would not in themselves make the satellite survivable. There were, and still are futuristic schemes aplenty being studied (laser and charged-particle satellites, "convoying," etc.), but nothing available for the near term that could even cope with our own MHV interceptor. So by insisting upon an ASAT solution to one problem, the military services are exposing themselves to a vast range

8. U.S. Congress, Senate Subcommittee of the Committee on Armed Services, Hearings, Authorization for Appropriations FY 1980, 96th Congress, First session, Part 6, p. 3027.
9. For FY 1980, funding of $80.5 million was requested for "space defense systems," all of it for various ASAT programs. An additional $30 million was requested for "satellite survivability," of which $11.6 million was for actual survivability technology. Congress has shown reluctance to approve even these modest funding levels.

of problems for the operation of all U.S. military forces, given their dependence upon satellite systems.

Problems of this sort convinced President Carter to add ASAT restraints to the list of arms control topics that he raised with the Soviet Union in the early days of his administration. The matter was broached with Moscow in March, 1977, and the sides subsequently agreed that a joint "working group" on the issue should be established. A year of delay then followed as the United States prepared for substantive negotiations. During this time, policy flesh was added to the spare skeleton of President Carter's initial proposal by a U.S. inter-agency study group, staffed by representatives from the NSC, the Defense Department, State, the Joint Chiefs, the Arms Control and Disarmament Agency, the CIA, and NASA. By this path, the two sides reached the negotiating table at Helsinki in June, 1978.

Approaches to the Control of ASAT Weapons

Public statements by the Carter Administration regarding its specific goals or proposals at the ASAT negotiations have been quite spare: the United States seeks comprehensive and verifiable limits on ASAT capabilities, and in the event such limits cannot be negotiated, it will acquire an ASAT capability of its own. Nonetheless, we can consider what an ASAT agreement might contain, if it is to serve American security interests.

Currently, the U.S. and Soviet Union are party to a series of international treaties that offer some margin of protection to satellites, although the sides have not directly addressed ASAT weapons in previous arms control talks. None of these existing accords, however, would serve as well in stemming an ASAT arms competition as a new treaty specifically focused on these weapons. For instance, provisions of the Limited Test Ban Treaty (1963) and the Outer Space Treaty (1967) would ban the sides from placing nuclear-armed ASAT weapons into orbit and would prohibit them from detonating nuclear warheads in outer space. But nuclear-armed interceptors are only one (and perhaps the least likely) type of potential ASAT weapon. Hence, the restrictions in these two accords certainly do not exhaust the range of constraints needed.[10]

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10. Unofficially, the Soviets have claimed broad scope for the Outer Space Treaty in banning ASAT systems. A TASS broadcast on April 4, 1977, stated that the United States had a "secret program to create means of destroying 'enemy satellites'" (evidently a reference to the MHV

Acts of interference with satellites are also in partial measure covered by several agreements. Article II of the Accidents Measures Agreement (1971) addresses interference with early warning systems, of which satellites would be one part, if such interference "could create a risk of outbreak of nuclear war." But this accord only obligates the sides to "notify each other immediately" when such interference is detected. By implication, however, if such acts of interference could indeed pose a risk of war, then the two sides would be obliged to refrain from such interference with early warning systems under the Agreement on the Prevention of Nuclear War (1974). There are also a number of general regulations governing radio-frequency interference contained in the Convention of the International Telecommunications Union, whose intention is to provide for the orderly use of the airwaves. Further constraints on interference are contained in the agreements of SALT I and II, where interference with satellites serving as part of "national technical means of verification" is prohibited.

The deficiency of these accords is that they govern only some attacks with ASAT weapons and only certain forms of interference. They do not address the whole range of threats nor other provocative aspects of an arms competition such as testing or deployment of ASAT systems. The goal of a new ASAT agreement would be to supplement, not to supplant the obligations of these existing treaties.

There are two basic approaches that could be taken in drafting an ASAT agreement: define in detail what an ASAT weapon consists of and ban all such weapons; or, ban the testing, deployment, or use of any weapon in a manner appropriate for attacking satellites. The contrast here is between banning things and banning actions.

Banning itemized things has numerous difficulties. Overly explicit itemizations of things which are prohibited can provide a road map for circumventing the intent of a treaty while remaining within its letter. However fertile the imaginations of treaty draftsmen in anticipating possible ASAT weapon designs, there will always be new technologies or techniques that

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project). TASS asserted that even an R&D program along these lines was "in direct violation" of the Outer Space Treaty. It is not clear what to make of this assertion, since by the same principle, the ongoing Soviet ASAT interceptor program would also have been in violation of the Treaty. In an equally broad interpretation, the TASS broadcast held that the U.S. Space Shuttle program was also banned under the same treaty. Officially, the Soviets have asserted that the Outer Space Treaty does not prohibit them from taking whatever action they choose against satellites engaged in military or other hostile acts against the Soviet Union.

will be overlooked. A treaty highly explicit in its definitions entails the risk of implying that any unspecified item is thus not subject to constraint. Yet another problem is that many of the capabilities that would be incorporated in an ASAT weapon (e.g., homing and maneuvering capabilities) may also be present in other space vehicles. Any attempt to ban all hardware with such capabilities could cripple non-ASAT space programs. Similarly, attempts to define and prohibit all equipment technically capable of electronic interference with satellites could cripple vital early warning radars and space communications systems (and could tell the other side precisely how vulnerable our satellites were to which kinds of electronic interference).

The inadvisability or simple impossibility of minutely defining all the restricted features of all conceivable ASAT weapons thus draws our attention to the second approach: banning ASAT activities, regardless of the equipment used. A model for this approach is the ABM Treaty, which broadly specifies and then restricts systems according to their use, i.e., any "system to counter strategic ballistic missiles or their elements in flight trajectory" (Article II.1). An ASAT agreement following this approach would contain two major obligations: 1) each side would agree not to use, not to deploy, and not to test any weapon or system for damaging or destroying satellites; and 2) each side would agree not to interfere with the functioning of the other's satellites. Testing in this context would refer to tests against targets in space. Other R&D on ASAT technologies, if confined to the laboratory, would not be subject to constraint. A ban on *all* R&D would be exceptionally difficult to verify, and as long as tests of ASAT prototypes against targets in simulated attacks are banned, neither side need fear that the other will acquire a high-confidence, agile ASAT system on the basis of lab work alone.

Treaty provisions along these lines would provide a number of benefits. The benefits from a prohibition on interference would be more modest but still worthwhile. It would be impractical to ban all equipment technically capable of interfering with satellites, so a ban only on acts of interference would not in itself eliminate all dangers. However, it would enhance the effectiveness of satellites in the normal course of things (something worth having especially in the case of intelligence satellites), it would diminish the chance of provocative acts involving all satellites, and it would prohibit the Soviets from practicing interference techniques on our satellites.

Major benefits would come from the ban on testing, deployment, and use of weapons for damaging or destroying satellites, for this would stunt the growth of offensive ASAT technologies while giving free rein to defensive

measures for protecting satellites. These provisions are crafted to have minimal adverse impact upon other, non-ASAT space programs. And some may regard this as a weakness rather than a virtue. A critic with imagination, for instance, might argue that the maneuverable *Progress* resupply vehicles used by the Soviets in their SALYUT manned space laboratory program could also be used to ram U.S. satellites, and thus must be banned if an ASAT agreement is to have any value. But this casts the alternatives too starkly. While some residual hazards from other space vehicles are conceivable, it is hard to see them as a compelling reason for abandoning ourselves entirely to unrestrained ASAT competition. Our ability to protect our satellites through some modest defensive measures will obviously be greater if the residual ASAT threat comes only from hardware designed for other purposes, banned from ASAT testing, and pressed into service only in an *ad hoc* way during conflict. An ASAT agreement should not induce us to be complacent about the survivability of our satellites. But it does offer a promising, indeed the only prospect of reducing the survivability problem to manageable proportions.

There are additional provisions necessary in an ASAT accord. The Soviet Union has already tested an ASAT interceptor, and this asymmetry must be addressed. There are strong voices in the U.S. government, particularly in the military services, which urge delay in any negotiations until the United States has tested a comparable ASAT capability. But advocates of this policy have not proposed a U.S. ASAT system "comparable" to the Soviets', that is, based upon 1960s technology. The U.S. MHV would be orders of magnitude more advanced. Moreover, a general promise from the United States to negotiate restraints "someday" when we catch up to Soviet capabilities does not offer the Soviets much incentive to restrain their own ASAT program. In the interim, they might well conduct ASAT tests with an improved interceptor or against higher altitude targets, thus multiplying the defensive problems for U.S. satellites.

To get around these difficulties, some have argued for a two-tier ban, prohibiting high altitude tests altogether while temporarily permitting ASAT tests below some threshold (e.g., below 2,000 nm). This would supposedly give the United States a chance to match the current Soviet capability while preventing the Soviets from extending their threat to higher U.S. satellites. But this proposal has technical flaws. ASAT weapons for attacking higher altitude satellites do have more exacting performance requirements, but systems meeting these rigorous standards could be constructed and amply tested

against targets below the threshold altitude. The practical consequence of a two-tier ban, therefore, would be the same as having no test ban at all.

The preferable course for dealing with the current asymmetry in ASAT capability is to require the Soviets to dismantle their present ASAT system. Getting them to give up a military capability in which they enjoy a current lead will not be easy. Yet the Soviets must certainly anticipate that the United States will engage them in a costly ASAT competition if there is no ASAT ban. Hence, the issue for the Soviets is the same as for the Americans—is it profitable to push arms competition in an arena where neither side can hope to sustain an operational advantage? Soviet willingness to accept limitations and even substantial reductions in strategic arms at SALT (including abstaining from extensive ABM defenses altogether) suggests that the Soviets are open to such arguments.

Compliance with these ASAT restrictions would be verified by the extensive intelligence and space surveillance facilities already available and being acquired by the United States. The Space Detection and Tracking System (SPADATS) currently enables the U.S. to detect, classify, and maintain an updated computer catalog of the identity and orbit of all space objects—currently in excess of 4,000 satellites, pieces of debris, etc. The completion of the GEODSS high-altitude tracking system now under construction will enable SPADATS to monitor objects as small as one foot in diameter in orbits up to 23,000 nm. The array of electronic and optical sensors deployed around and over the Soviet Union permits comparable tracking and classification of Soviet missile and space launches. Together these facilities would verify the ban on ASAT testing, deployment, and use by monitoring for telltale features of an ASAT program. These would vary from weapon to weapon, but any ASAT system would expose itself at many points to detection: e.g., direct-ascent, co-orbital, and space-based laser interceptors would require launch preparations, launching, and maneuvering to altitudes and orbital planes appropriate for ASAT attacks; ground- or space-based lasers or charged particle weapons would involve the rapid discharge of high levels of energy and possible waste products of power generation; in all cases, the damage, intense heating, destruction, or displacement from its orbit of a target could be detectable.

We should consider that the Soviets might press along with a variety of untested ASAT weapons as far as laboratory work could carry them, looking ahead to using untested systems in a conflict; or alternatively that they might conduct covert tests in the guise of other space programs. But neither of

these schemes would be very promising. The more technically sophisticated a weapon is, the more military planners will insist upon full-scale testing. Indeed, if the kill mechanism of the weapon requires high accuracy (as all non-nuclear and laser ASATs would), full-scale testing could be indispensable to confirm whether the design works at all. Given past surprises and catastrophes in test programs of advanced weapons, few military commanders would be satisfied with an ASAT device tested only in the lab or covertly, in pieces, under the cover of other space programs. Moreover, any covert program would have to reckon with the close scrutiny to which Soviet space programs are subjected by U.S. intelligence agencies, with their long experience at sifting the unusual from the familiar. To have confidence in successfully and repeatedly evading such scrutiny, the Soviets would have to know in minute detail what U.S. intelligence looks for and has already learned.

Verifying the treaty provision on interference would require additional monitoring facilities beyond those used to monitor testing. But again these are facilities that the U.S. is acquiring and will continue to improve upon. Precisely because attacks on, or interference with our satellites might be a prelude to other hostile acts, the United States has an interest in knowing when its satellites are being tampered with and by whom, even in the absence of an ASAT agreement. Detectors mounted on satellites for monitoring the nature and source of interference are therefore needed in any case, and they can also serve the purpose of verifying the prohibitions in an ASAT treaty. In fact, an ASAT accord would considerably enhance the usefulness of such detectors in providing warning. Unless deliberate interference with satellites is banned, U.S. satellites would be vulnerable to repeated "spoofing," until a string of such false alarms had dulled our alertness to an actual attack. Under a general ban on interference, any episode of this sort would be a red flag warning us to pay attention.[11]

The most troublesome verification problem will be posed by the current Soviet ASAT system. The Soviet system uses a number of components and facilities that are shared with other Soviet space missions and weapon systems. The verification issue here is not one of knowing whether the Soviet

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11. All communications and electronic intelligence satellites have some inherent capability for detecting and locating radio-frequency interference. President Carter, in a Presidential Decision Memorandum of May, 1978, has ordered that monitoring and survivability equipment be incorporated in all future U.S. satellite systems. The Defense Department has already begun to implement the President's directive.

ASAT system proper has been dismantled or is no longer being tested. The question is whether it could be rapidly re-assembled on a jury-rigged basis, using these shared facilities. The United States would have a hedge against this problem, because it would be free to implement survivability measures to make its satellites progressively less vulnerable to the older technology embodied in the Soviet ASAT interceptor. And a prolonged period of not testing the system would also erode Soviet confidence in any such "break-out" schemes. Nonetheless, the thoroughness of Soviet dismantling efforts will be an important issue in public evaluation of any potential ASAT treaty, and Soviet willingness to go the extra mile on this matter will undoubtedly be taken as a hallmark of Soviet earnestness in ASAT arms control.

The Soviets have thus far shown important signs of taking these ASAT issues seriously. As head of their ASAT delegation, the Soviets appointed Oleg N. Khlestov, an authority on space law with service as the Chief of the Treaty and Legal Department in the Ministry of Foreign Affairs. At the first round of talks in Helsinki, the Soviets insisted upon labeling the sessions as no more than "preliminary consultations," reflecting the uncertainties of dealing with a novel topic. But by the second round in Bern (January 23–February 16, 1979), they were willing to make the symbolic transition to "negotiations seeking concrete results." Round three in Vienna (April 23–June 17, 1979) was equally frank and businesslike in the exchange of viewpoints and tentative proposals. The Soviet willingness to suspend their ASAT testing program while the talks were in progress may also be taken as a sign of seriousness. Certainly the United States loses nothing by continuing to explore Soviet interest in ASAT constraints along the lines sketched here. The Defense Department's R&D program on ASAT systems is vigorous enough to protect our other options, should ASAT talks come to naught.

Conclusion

Arms control proposals have not enjoyed a congenial political atmosphere in the United States, even before the Soviet invasion of Afghanistan. As a consequence, advocates of arms control have often been more zealous in asserting the virtues of their proposals than prudence would counsel. That temptation should be resisted in the case of an ASAT agreement. The limitations on ASAT competition outlined here are no panacea; they offer to contrain the threats to U.S. satellites to manageable proportions, not to eliminate each and every threat now and forever. As such, these measures

will be unsatisfying to those who insist that, to be acceptable, arms control accords must be foolproof and comprehensive in averting all threats.

The virtues of an ASAT agreement are best measured by considering its most likely alternative—an unbridled competition in space weaponry. Enthusiasts of the U.S. MHV project may speak with delight, as one White House aide did, of "sweeping the skies clean in twenty-four hours." Yet if the MHV is going to be as nimble as its project managers claim, then clearly the United States ought to be planning now for a transition to lesser dependence upon satellites. For in the absence of agreed restraints, there is nothing to prevent the Soviets from acquiring an ASAT capability comparable to the MHV and doing their own sweeping. Yet instead, the Defense Department has been doing just the opposite, drifting toward greater reliance upon space systems. Advocates of the MHV talk as if this growing dependency in the emerging era of space warfare is a problem manageable through an old solution—the doctrine of deterrence—yet even the Defense Department undersecretary overseeing the MHV project sees no promise in that doctrine.

Constraining threats to U.S. interests through the exercise of enlightened mutual restraint on the acquisition of weapons is a practice that does not come easily to American policymakers. It requires both vision and discipline to break from the habit of believing that any weapon which can be built ought to be built; that any advantage within grasp, however fleeting and costly in the long term, ought to be seized. We will not have acted wisely if, from untempered force of habit, we reject this opportunity to explore limits on arms competition in outer space.

V. RESOURCE ALLOCATION AMONG COMPETING NATIONAL PRIORITIES

205 Special Message to the Congress on Urgent National Needs. *May 25, 1961*

[Delivered in person before a joint session]

Mr. Speaker, Mr. Vice President, my co-partners in Government, gentlemen—and ladies:

The Constitution imposes upon me the obligation to "from time to time give to the Congress information of the State of the Union." While this has traditionally been interpreted as an annual affair, this tradition has been broken in extraordinary times.

These are extraordinary times. And we face an extraordinary challenge. Our strength as well as our convictions have imposed upon this nation the role of leader in freedom's cause.

No role in history could be more difficult or more important. We stand for freedom.

Reproduced from Public Papers of the Presidents of the United States: John F. Kennedy, 1961. Washington, G.P.O., 1962. p. 396-406.

That is our conviction for ourselves—that is our only commitment to others. No friend, no neutral and no adversary should think otherwise. We are not against any man—or any nation—or any system—except as it is hostile to freedom. Nor am I here to present a new military doctrine, bearing any one name or aimed at any one area. I am here to promote the freedom doctrine.

I.

The great battleground for the defense and expansion of freedom today is the whole southern half of the globe—Asia, Latin America, Africa and the Middle East—the lands of the rising peoples. Their revolution is the greatest in human history. They seek an end to injustice, tyranny, and exploitation. More than an end, they seek a beginning.

And theirs is a revolution which we would support regardless of the Cold War, and regardless of which political or economic route they should choose to freedom.

For the adversaries of freedom did not create the revolution; nor did they create the conditions which compel it. But they are seeking to ride the crest of its wave—to capture it for themselves.

Yet their aggression is more often concealed than open. They have fired no missiles; and their troops are seldom seen. They send arms, agitators, aid, technicians and propaganda to every troubled area. But where fighting is required, it is usually done by others—by guerrillas striking at night, by assassins striking alone—assassins who have taken the lives of four thousand civil officers in the last twelve months in Vietnam alone—by subversives and saboteurs and insurrectionists, who in some cases control whole areas inside of independent nations.[1]

With these formidable weapons, the adversaries of freedom plan to consolidate their territory—to exploit, to control, and finally to destroy the hopes of the world's newest nations; and they have ambition to do it before the end of this decade. It is a contest of will and purpose as well as force and violence—a battle for minds and souls as well as lives and territory. And in that contest, we cannot stand aside.

We stand, as we have always stood from our earliest beginnings, for the independence and equality of all nations. This nation was born of revolution and raised in freedom. And we do not intend to leave an open road for despotism.

There is no single simple policy which meets this challenge. Experience has taught us that no one nation has the power or the wisdom to solve all the problems of the world or manage its revolutionary tides—that extending our commitments does not always increase our security—that any initiative carries with it the risk of a temporary defeat—that nuclear weapons cannot prevent subversion—that no free people can be kept free without will and energy of their own—

[1] At this point the following paragraph, which appears in the text as signed and transmitted to the Senate and House of Representatives, was omitted in the reading of the message:

They possess a powerful intercontinental striking force, large forces for conventional war, a well-trained underground in nearly every country, the power to conscript talent and manpower for any purpose, the capacity for quick decisions, a closed society without dissent or free information, and long experience in the techniques of violence and subversion. They make the most of their scientific successes, their economic progress and their pose as a foe of colonialism and friend of popular revolution. They prey on unstable or unpopular governments, unsealed, or unknown boundaries, unfilled hopes, convulsive change, massive poverty, illiteracy, unrest and frustration.

and that no two nations or situations are exactly alike.

Yet there is much we can do—and must do. The proposals I bring before you are numerous and varied. They arise from the host of special opportunities and dangers which have become increasingly clear in recent months. Taken together, I believe that they can mark another step forward in our effort as a people. I am here to ask the help of this Congress and the nation in approving these necessary measures.

II. ECONOMIC AND SOCIAL PROGRESS AT HOME

The first and basic task confronting this nation this year was to turn recession into recovery. An affirmative anti-recession program, initiated with your cooperation, supported the natural forces in the private sector; and our economy is now enjoying renewed confidence and energy. The recession has been halted. Recovery is under way.

But the task of abating unemployment and achieving a full use of our resources does remain a serious challenge for us all. Large-scale unemployment during a recession is bad enough, but large-scale unemployment during a period of prosperity would be intolerable.

I am therefore transmitting to the Congress a new Manpower Development and Training program, to train or retrain several hundred thousand workers, particularly in those areas where we have seen chronic unemployment as a result of technological factors in new occupational skills over a four-year period, in order to replace those skills made obsolete by automation and industrial change with the new skills which the new processes demand.

It should be a satisfaction to us all that we have made great strides in restoring world confidence in the dollar, halting the outflow of gold and improving our balance of payments. During the last two months, our gold stocks actually increased by seventeen million dollars, compared to a loss of 635 million dollars during the last two months of 1960. We must maintain this progress—and this will require the cooperation and restraint of everyone. As recovery progresses, there will be temptations to seek unjustified price and wage increases. These we cannot afford. They will only handicap our efforts to compete abroad and to achieve full recovery here at home. Labor and management must—and I am confident that they will—pursue responsible wage and price policies in these critical times. I look to the President's Advisory Committee on Labor-Management Policy to give a strong lead in this direction.

Moreover, if the budget deficit now increased by the needs of our security is to be held within manageable proportions, it will be necessary to hold tightly to prudent fiscal standards; and I request the cooperation of the Congress in this regard—to refrain from adding funds or programs, desirable as they may be, to the Budget—to end the postal deficit, as my predecessor also recommended, through increased rates—a deficit incidentally, this year, which exceeds the fiscal 1962 cost of all the space and defense measures that I am submitting today—to provide full pay-as-you-go highway financing—and to close those tax loopholes earlier specified. Our security and progress cannot be cheaply purchased; and their price must be found in what we all forego as well as what we all must pay.

III. ECONOMIC AND SOCIAL PROGRESS ABROAD

I stress the strength of our economy because it is essential to the strength of our

nation. And what is true in our case is true in the case of other countries. Their strength in the struggle for freedom depends on the strength of their economic and their social progress.

We would be badly mistaken to consider their problems in military terms alone. For no amount of arms and armies can help stabilize those governments which are unable or unwilling to achieve social and economic reform and development. Military pacts cannot help nations whose social injustice and economic chaos invite insurgency and penetration and subversion. The most skillful counter-guerrilla efforts cannot succeed where the local population is too caught up in its own misery to be concerned about the advance of communism.

But for those who share this view, we stand ready now, as we have in the past, to provide generously of our skills, and our capital, and our food to assist the peoples of the less-developed nations to reach their goals in freedom—to help them before they are engulfed in crisis.

This is also our great opportunity in 1961. If we grasp it, then subversion to prevent its success is exposed as an unjustifiable attempt to keep these nations from either being free or equal. But if we do not pursue it, and if they do not pursue it, the bankruptcy of unstable governments, one by one, and of unfilled hopes will surely lead to a series of totalitarian receiverships.

Earlier in the year, I outlined to the Congress a new program for aiding emerging nations; and it is my intention to transmit shortly draft legislation to implement this program, to establish a new Act for International Development, and to add to the figures previously requested, in view of the swift pace of critical events, an additional 250 million dollars for a Presidential Contingency Fund, to be used only upon a Presidential determination in each case, with regular and complete reports to the Congress in each case, when there is a sudden and extraordinary drain upon our regular funds which we cannot foresee—as illustrated by recent events in Southeast Asia—and it makes necessary the use of this emergency reserve. The total amount requested—now raised to 2.65 billion dollars—is both minimal and crucial. I do not see how anyone who is concerned—as we all are—about the growing threats to freedom around the globe—and who is asking what more we can do as a people—can weaken or oppose the single most important program available for building the frontiers of freedom.

IV.

All that I have said makes it clear that we are engaged in a world-wide struggle in which we bear a heavy burden to preserve and promote the ideals that we share with all mankind, or have alien ideals forced upon them. That struggle has highlighted the role of our Information Agency. It is essential that the funds previously requested for this effort be not only approved in full, but increased by 2 million, 400 thousand dollars, to a total of 121 million dollars.

This new request is for additional radio and television to Latin America and Southeast Asia. These tools are particularly effective and essential in the cities and villages of those great continents as a means of reaching millions of uncertain peoples to tell them of our interest in their fight for freedom. In Latin America, we are proposing to increase our Spanish and Portuguese broadcasts to a total of 154 hours a week, compared to 42 hours today, none of which is in Portuguese, the language of about one-third of the people of South America. The Soviets, Red Chinese and satellites already broadcast into

Latin America more than 134 hours a week in Spanish and Portuguese. Communist China alone does more public information broadcasting in our own hemisphere than we do. Moreover, powerful propaganda broadcasts from Havana now are heard throughout Latin America, encouraging new revolutions in several countries.

Similarly, in Laos, Vietnam, Cambodia, and Thailand, we must communicate our determination and support to those upon whom our hopes for resisting the communist tide in that continent ultimately depend. Our interest is in the truth.

V. OUR PARTNERSHIP FOR SELF-DEFENSE

But while we talk of sharing and building and the competition of ideas, others talk of arms and threaten war. So we have learned to keep our defenses strong—and to cooperate with others in a partnership of self-defense. The events of recent weeks have caused us to look anew at these efforts.

The center of freedom's defense is our network of world alliances, extending from NATO, recommended by a Democratic President and approved by a Republican Congress, to SEATO, recommended by a Republican President and approved by a Democratic Congress. These alliances were constructed in the 1940's and 1950's—it is our task and responsibility in the 1960's to strengthen them.

To meet the changing conditions of power—and power relationships have changed—we have endorsed an increased emphasis on NATO's conventional strength. At the same time we are affirming our conviction that the NATO nuclear deterrent must also be kept strong. I have made clear our intention to commit to the NATO command, for this purpose, the 5 Polaris submarines originally suggested by President Eisenhower, with the possibility, if needed, of more to come.

Second, a major part of our partnership for self-defense is the Military Assistance Program. The main burden of local defense against local attack, subversion, insurrection or guerrilla warfare must of necessity rest with local forces. Where these forces have the necessary will and capacity to cope with such threats, our intervention is rarely necessary or helpful. Where the will is present and only capacity is lacking, our Military Assistance Program can be of help.

But this program, like economic assistance, needs a new emphasis. It cannot be extended without regard to the social, political and military reforms essential to internal respect and stability. The equipment and training provided must be tailored to legitimate local needs and to our own foreign and military policies, not to our supply of military stocks or a local leader's desire for military display. And military assistance can, in addition to its military purposes, make a contribution to economic progress, as do our own Army Engineers.

In an earlier message, I requested 1.6 billion dollars for Military Assistance, stating that this would maintain existing force levels, but that I could not foresee how much more might be required. It is now clear that this is not enough. The present crisis in Southeast Asia, on which the Vice President has made a valuable report—the rising threat of communism in Latin America—the increased arms traffic in Africa—and all the new pressures on every nation found on the map by tracing your fingers along the borders of the Communist bloc in Asia and the Middle East—all make clear the dimension of our needs.

I therefore request the Congress to provide a total of 1.885 billion dollars for Military Assistance in the coming fiscal year—an

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amount less than that requested a year ago—but a minimum which must be assured if we are to help those nations make secure their independence. This must be prudently and wisely spent—and that will be our common endeavor. Military and economic assistance has been a heavy burden on our citizens for a long time, and I recognize the strong pressures against it; but this battle is far from over, it is reaching a crucial stage, and I believe we should participate in it. We cannot merely state our opposition to totalitarian advance without paying the price of helping those now under the greatest pressure.

VI. OUR OWN MILITARY AND INTELLIGENCE SHIELD

In line with these developments, I have directed a further reinforcement of our own capacity to deter or resist non-nuclear aggression. In the conventional field, with one exception, I find no present need for large new levies of men. What is needed is rather a change of position to give us still further increases in flexibility.

Therefore, I am directing the Secretary of Defense to undertake a reorganization and modernization of the Army's divisional structure, to increase its non-nuclear firepower, to improve its tactical mobility in any environment, to insure its flexibility to meet any direct or indirect threat, to facilitate its coordination with our major allies, and to provide more modern mechanized divisions in Europe and bring their equipment up to date, and new airborne brigades in both the Pacific and Europe.

And secondly, I am asking the Congress for an additional 100 million dollars to begin the procurement task necessary to re-equip this new Army structure with the most modern material. New helicopters, new armored personnel carriers, and new howitzers, for example, must be obtained now.

Third, I am directing the Secretary of Defense to expand rapidly and substantially, in cooperation with our Allies, the orientation of existing forces for the conduct of non-nuclear war, para-military operations and sub-limited or unconventional wars.

In addition, our special forces and unconventional warfare units will be increased and reoriented. Throughout the services new emphasis must be placed on the special skills and languages which are required to work with local populations.

Fourth, the Army is developing plans to make possible a much more rapid deployment of a major portion of its highly trained reserve forces. When these plans are completed and the reserve is strengthened, two combat-equipped divisions, plus their supporting forces, a total of 89,000 men, could be ready in an emergency for operations with but 3 weeks' notice—2 more divisions with but 5 weeks' notice—and six additional divisions and their supporting forces, making a total of 10 divisions, could be deployable with less than 8 weeks' notice. In short, these new plans will allow us to almost double the combat power of the Army in less than two months, compared to the nearly nine months heretofore required.

Fifth, to enhance the already formidable ability of the Marine Corps to respond to limited war emergencies, I am asking the Congress for 60 million dollars to increase the Marine Corps strength to 190,000 men. This will increase the initial impact and staying power of our three Marine divisions and three air wings, and provide a trained nucleus for further expansion, if necessary for self-defense.

Finally, to cite one other area of activities that are both legitimate and necessary as a means of self-defense in an age of hidden

perils, our whole intelligence effort must be reviewed, and its coordination with other elements of policy assured. The Congress and the American people are entitled to know that we will institute whatever new organization, policies, and control are necessary.

VII. CIVIL DEFENSE

One major element of the national security program which this nation has never squarely faced up to is civil defense. This problem arises not from present trends but from national inaction in which most of us have participated. In the past decade we have intermittently considered a variety of programs, but we have never adopted a consistent policy. Public considerations have been largely characterized by apathy, indifference and skepticism; while, at the same time, many of the civil defense plans have been so far-reaching and unrealistic that they have not gained essential support.

This Administration has been looking hard at exactly what civil defense can and cannot do. It cannot be obtained cheaply. It cannot give an assurance of blast protection that will be proof against surprise attack or guaranteed against obsolescence or destruction. And it cannot deter a nuclear attack.

We will deter an enemy from making a nuclear attack only if our retaliatory power is so strong and so invulnerable that he knows he would be destroyed by our response. If we have that strength, civil defense is not needed to deter an attack. If we should ever lack it, civil defense would not be an adequate substitute.

But this deterrent concept assumes rational calculations by rational men. And the history of this planet, and particularly the history of the 20th century, is sufficient to remind us of the possibilities of an irrational attack, a miscalculation, an accidental war, [or a war of escalation in which the stakes by each side gradually increase to the point of maximum danger] which cannot be either foreseen or deterred. It is on this basis that civil defense can be readily justifiable—as insurance for the civilian population in case of an enemy miscalculation. It is insurance we trust will never be needed—but insurance which we could never forgive ourselves for foregoing in the event of catastrophe.

Once the validity of this concept is recognized, there is no point in delaying the initiation of a nation-wide long-range program of identifying present fallout shelter capacity and providing shelter in new and existing structures. Such a program would protect millions of people against the hazards of radioactive fallout in the event of large-scale nuclear attack. Effective performance of the entire program not only requires new legislative authority and more funds, but also sound organizational arrangements.

Therefore, under the authority vested in me by Reorganization Plan No. 1 of 1958, I am assigning responsibility for this program to the top civilian authority already responsible for continental defense, the Secretary of Defense. It is important that this function remain civilian, in nature and leadership; and this feature will not be changed.

The Office of Civil and Defense Mobilization will be reconstituted as a small staff agency to assist in the coordination of these functions. To more accurately describe its role, its title should be changed to the Office of Emergency Planning.

As soon as those newly charged with these responsibilities have prepared new authorization and appropriation requests, such requests will be transmitted to the Congress for a much strengthened Federal-State civil

defense program. Such a program will provide Federal funds for identifying fallout shelter capacity in existing structures, and it will include, where appropriate, incorporation of shelter in Federal buildings, new requirements for shelter in buildings constructed with Federal assistance, and matching grants and other incentives for constructing shelter in State and local and private buildings.

Federal appropriations for civil defense in fiscal 1962 under this program will in all likelihood be more than triple the pending budget requests; and they will increase sharply in subsequent years. Financial participation will also be required from State and local governments and from private citizens. But no insurance is cost-free; and every American citizen and his community must decide for themselves whether this form of survival insurance justifies the expenditure of effort, time and money. For myself, I am convinced that it does.

VIII. DISARMAMENT

I cannot end this discussion of defense and armaments without emphasizing our strongest hope: the creation of an orderly world where disarmament will be possible. Our aims do not prepare for war—they are efforts to discourage and resist the adventures of others that could end in war.

That is why it is consistent with these efforts that we continue to press for properly safeguarded disarmament measures. At Geneva, in cooperation with the United Kingdom, we have put forward concrete proposals to make clear our wish to meet the Soviets half way in an effective nuclear test ban treaty—the first significant but essential step on the road towards disarmament. Up to now, their response has not been what we hoped, but Mr. Dean returned last night to Geneva, and we intend to go the last mile in patience to secure this gain if we can.

Meanwhile, we are determined to keep disarmament high on our agenda—to make an intensified effort to develop acceptable political and technical alternatives to the present arms race. To this end I shall send to the Congress a measure to establish a strengthened and enlarged Disarmament Agency.

IX. SPACE

Finally, if we are to win the battle that is now going on around the world between freedom and tyranny, the dramatic achievements in space which occurred in recent weeks should have made clear to us all, as did the Sputnik in 1957, the impact of this adventure on the minds of men everywhere, who are attempting to make a determination of which road they should take. Since early in my term, our efforts in space have been under review. With the advice of the Vice President, who is Chairman of the National Space Council, we have examined where we are strong and where we are not, where we may succeed and where we may not. Now it is time to take longer strides—time for a great new American enterprise—time for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on earth.

I believe we possess all the resources and talents necessary. But the facts of the matter are that we have never made the national decisions or marshalled the national resources required for such leadership. We have never specified long-range goals on an urgent time schedule, or managed our resources and our time so as to insure their fulfillment.

Recognizing the head start obtained by the Soviets with their large rocket engines, which gives them many months of lead-

time, and recognizing the likelihood that they will exploit this lead for some time to come in still more impressive successes, we nevertheless are required to make new efforts on our own. For while we cannot guarantee that we shall one day be first, we can guarantee that any failure to make this effort will make us last. We take an additional risk by making it in full view of the world, but as shown by the feat of astronaut Shepard, this very risk enhances our stature when we are successful. But this is not merely a race. Space is open to us now; and our eagerness to share its meaning is not governed by the efforts of others. We go into space because whatever mankind must undertake, free men must fully share.

I therefore ask the Congress, above and beyond the increases I have earlier requested for space activities, to provide the funds which are needed to meet the following national goals:

First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish. We propose to accelerate the development of the appropriate lunar space craft. We propose to develop alternate liquid and solid fuel boosters, much larger than any now being developed, until certain which is superior. We propose additional funds for other engine development and for unmanned explorations—explorations which are particularly important for one purpose which this nation will never overlook: the survival of the man who first makes this daring flight. But in a very real sense, it will not be one man going to the moon—if we make this judgment affirmatively, it will be an entire nation. For all of us must work to put him there.

Secondly, an additional 23 million dollars, together with 7 million dollars already available, will accelerate development of the Rover nuclear rocket. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the moon, perhaps to the very end of the solar system itself.

Third, an additional 50 million dollars will make the most of our present leadership, by accelerating the use of space satellites for world-wide communications.

Fourth, an additional 75 million dollars—of which 53 million dollars is for the Weather Bureau—will help give us at the earliest possible time a satellite system for world-wide weather observation.

Let it be clear—and this is a judgment which the Members of the Congress must finally make—let it be clear that I am asking the Congress and the country to accept a firm commitment to a new course of action—a course which will last for many years and carry very heavy costs: 531 million dollars in fiscal '62—an estimated seven to nine billion dollars additional over the next five years. If we are to go only half way, or reduce our sights in the face of difficulty, in my judgment it would be better not to go at all.

Now this is a choice which this country must make, and I am confident that under the leadership of the Space Committees of the Congress, and the Appropriating Committees, that you will consider the matter carefully.

It is a most important decision that we make as a nation. But all of you have lived through the last four years and have seen the significance of space and the adventures in

space, and no one can predict with certainty what the ultimate meaning will be of mastery of space.

I believe we should go to the moon. But I think every citizen of this country as well as the Members of the Congress should consider the matter carefully in making their judgment, to which we have given attention over many weeks and months, because it is a heavy burden, and there is no sense in agreeing or desiring that the United States take an affirmative position in outer space, unless we are prepared to do the work and bear the burdens to make it successful. If we are not, we should decide today and this year.

This decision demands a major national commitment of scientific and technical manpower, materiel and facilities, and the possibility of their diversion from other important activities where they are already thinly spread. It means a degree of dedication, organization and discipline which have not always characterized our research and development efforts. It means we cannot afford undue work stoppages, inflated costs of material or talent, wasteful interagency rivalries, or a high turnover of key personnel.

New objectives and new money cannot solve these problems. They could in fact, aggravate them further—unless every scientist, every engineer, every serviceman, every technician, contractor, and civil servant gives his personal pledge that this nation will move forward, with the full speed of freedom, in the exciting adventure of space.

X. CONCLUSION

In conclusion, let me emphasize one point. It is not a pleasure for any President of the United States, as I am sure it was not a pleasure for my predecessors, to come before the Congress and ask for new appropriations which place burdens on our people. I came to this conclusion with some reluctance. But in my judgment, this is a most serious time in the life of our country and in the life of freedom around the globe, and it is the obligation, I believe, of the President of the United States to at least make his recommendations to the Members of the Congress, so that they can reach their own conclusions with that judgment before them. You must decide yourselves, as I have decided, and I am confident that whether you finally decide in the way that I have decided or not, that your judgment—as my judgment—is reached on what is in the best interests of our country.

In conclusion, let me emphasize one point: that we are determined, as a nation in 1961 that freedom shall survive and succeed—and whatever the peril and set-backs, we have some very large advantages.

The first is the simple fact that we are on the side of liberty—and since the beginning of history, and particularly since the end of the Second World War, liberty has been winning out all over the globe.

A second great asset is that we are not alone. We have friends and allies all over the world who share our devotion to freedom. May I cite as a symbol of traditional and effective friendship the great ally I am about to visit—France. I look forward to my visit to France, and to my discussion with a great Captain of the Western World, President de Gaulle, as a meeting of particular significance, permitting the kind of close and ranging consultation that will strengthen both our countries and serve the common purposes of world-wide peace and liberty. Such serious conversations do not require a pale unanimity—they are rather the instruments of trust and understanding over a long road.

A third asset is our desire for peace. It is sincere, and I believe the world knows it.

We are proving it in our patience at the test-ban table, and we are proving it in the UN where our efforts have been directed to maintaining that organization's usefulness as a protector of the independence of small nations. In these and other instances, the response of our opponents has not been encouraging.

Yet it is important to know that our patience at the bargaining table is nearly inexhaustible, though our credulity is limited—that our hopes for peace are unfailing, while our determination to protect our security is resolute. For these reasons I have long thought it wise to meet with the Soviet Premier for a personal exchange of views. A meeting in Vienna turned out to be convenient for us both; and the Austrian government has kindly made us welcome. No formal agenda is planned and no negotiations will be undertaken; but we will make clear America's enduring concern is for both peace *and* freedom—that we are anxious to live in harmony with the Russian people—that we seek no conquests, no satellites, no riches—that we seek only the day when "nation shall not lift up sword against nation, neither shall they learn war any more."

Finally, our greatest asset in this struggle is the American people—their willingness to pay the price for these programs—to understand and accept a long struggle—to share their resources with other less fortunate people—to meet the tax levels and close the tax loopholes I have requested—to exercise self-restraint instead of pushing up wages or prices, or over-producing certain crops, or spreading military secrets, or urging unessential expenditures or improper monopolies or harmful work stoppages—to serve in the Peace Corps or the Armed Services or the Federal Civil Service or the Congress—to strive for excellence in their schools, in their cities and in their physical fitness and that of their children—to take part in Civil Defense—to pay higher postal rates, and higher payroll taxes and higher teachers' salaries, in order to strengthen our society—to show friendship to students and visitors from other lands who visit us and go back in many cases to be the future leaders, with an image of America—and I want that image, and I know you do, to be affirmative and positive—and, finally, to practice democracy at home, in all States, with all races, to respect each other and to protect the Constitutional rights of all citizens.

I have not asked for a single program which did not cause one or all Americans some inconvenience, or some hardship, or some sacrifice. But they have responded—and you in the Congress have responded to your duty—and I feel confident in asking today for a similar response to these new and larger demands. It is heartening to know, as I journey abroad, that our country is united in its commitment to freedom—and is ready to do its duty.

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Reproduced from The future environment: Introduction. In Humes, Katheryn H., and others. The future environment: U.S. and world trends. [Prepared by Forecasting International, Ltd., and its subcontractor, The Futures Group.] Washington, National Aeronautics and Space Administration, [Available from NTIS: N7618970] 1975. Introduction (36 p.)

THE FUTURE ENVIRONMENT: INTRODUCTION

1. Overview:

In June 1975, the Administrator of The National Aeronautics and Space Administration established a Study Group of twenty NASA scientists, engineers and managers to conduct a study of the role of civilian space flight in the U.S. in the period 1980-2000.

The study was to last one year and, although conducted by a NASA group, was expected to draw extensively on outside consultants and on expertise in disciplines not indigenous to NASA. The study was intended to be contextual; i.e., that is, the study topics were to be considered within the framework of other societal activities. This direction was set by two of the five objectives the Administrator established for the study:

1. "To identify social and economic challenges which can benefit from space."
2. "To relate goals and objectives of civilian space activities to national goals and objectives."

In recognition of its lack of expertise in economics, sociology, international affairs, and the future, the Study Group undertook a number of activities to bolster its knowledge and expand its horizons. A major effort along these lines was a contract with Forecasting International and The Futures Group which has resulted in this report to the Study Group. Included in this support to the Study Group, were extensive contacts with Working Group II (Future Environments) of the study team, with other members of the Group, and frequent participation in the Study Group discussions and deliberations on the relationships between space flight activities and the future economic, intellectual and other needs of the American Society.

Specifically, the basic contract required support, as follows:

a) Methodologies of technological forecasting

b) Lectures and seminars on contextual planning

c) Comments on the "system design" of the Outlook for Space Study

d) Literature searches and reports on the future

e) Participation in Study Group activities

and consultation on related matters as required. In addition, during the initial phases of the study, Forecasting International provided considerable support to the Technology Forecasting Task being performed by JPL for the OFS Study. Tutorial lectures on methodologies, existing technology forecasts and editorial assistance were furnished. This work is not reported here but was included, where appropriate, in the Working Group V (Technology)[1] report.

An early task of the Working Group II, and of the Study Group, was the examination of the various methodologies by which the future could be characterized and the choice of one for use as a framework for evaluating the differing contributions that various space flight activities could make in the future. Our early reports examined three approaches for consideration by the Study Group.[2,3,4] One developed several scenarios, as forecasts of

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[1] A Forecast of Space Technology, 1980-2000, Final Draft, Report for Working Group V, OFS Study Group, J. James and R. R. McDonald, JPL, Principal Authors, July 1975.

[2] Theodore J. Gordon, et al, Prospective Crises: Some Challenges to Planning, (The Futures Group: Glastonbury, Connecticut), 4 September 1974.

[3] Kathryn H. Humes, et al, Forecasts and Assessments of Future Civilian Space Activities (Forecasting International, Ltd.: Arlington, Virginia), 28 September 1974.

[4] Kathryn H. Humes, et al, Two Alternative Futures and Their Impact, (Forecasting International, Ltd.: Arlington, Virginia), 21 October 1974.

the future; another was an attempt to develop a set of national goals and objectives; and the third was a collection of brief essays on some potential crises that could radically change the future.

The scenarios, four in number, were derived from a "scenario map" in which the two dimensions were (a) the degree to which the U.S. Government interveres in domestic economic activities and (b) the degree to which the U.S. participates in the solution of international problems. Of the four scenarios possible with these two dimensions; (a) nationalist - laissez faire, (b) nationalist - planned, (c) cooperative - laissez faire, and (d) cooperative - planned, two were chosen for more detailed description; i.e., (a) and (d). Finally, in this approach, space programs which best fit each of the two future scenarios were discussed.

The second approach developed was to forecast and assess future space activities in the context of national goals and objectives. The immediate difficulty with this approach is that there does not exist in one place for all to know a statement of America's goals as a nation. The report surveyed the various studies and public polls on goals and objectives, selected a set which seemed most reasonable to the investigators and proceeded, in a semi-quantitative way, to weigh the contributions that space activities might make to meeting these various goals. The result was a matrix of numbers showing the contribution of space missions to weighted national goals.

The third approach was to develop a set of brief essays or descriptions of potential future crises which, it was deemed, would prompt policy analysis and policy-making by the Government. In the time frame of the next twenty-five years, the following crises were discussed: nuclear war, food shortages,

deterioration of the biosphere, imbalances in the distribution of wealth, shortages of mineral resources, energy sources and technology and inflation and international economics.

At the Study Group meeting at Marshall Space Flight Center in November 1974, these and other alternative approaches to examining the future were reviewed. The Study Group decided to proceed with an approach based on the potential crises essays, since, it was felt, this would provide the Group an indepth background on what was happening in society but would leave the Group itself free to evaluate space activities in the context of that background. The balance of the Forecasting International/The Futures Group study has been the preparation of a series of 20 essays on various selected issues in U.S. and World Trends.

The approach taken is outlined in the attached Figure 1. Six topics or Trends were selected: Non-renewable resources (including energy), Population and Food, etc. and within each of these Trends, a number of Issues are identified. One criterion for the choice of an Issue was that it might have, *a priori*, some direct or indirect implications for space flight in the future. In-depth analyses and narratives on each of the Issues were prepared. An overview or brief on each of the Trends was written.

This "trends and issues" approach was not intended to be comprehensive or in any way exhaustive. The specifics in one essay may conflict with those of another. There are many different views of what is changing, and how, in today's world. This approach was intended to provide the Study Group as wide-ranging and diverse a set of information as was possible within the time and resources available.

FIGURE 1

FUTURE ENVIRONMENTS: U.S. AND WORLD TRENDS

Non-renewable Resources:

- Minerals
- Energy - Energy and Growth

International Conflict:

- Economic Disparities
- Shared Resources
- Warfare

Population and Food:

- Fourth World
- Food and Fourth World Starvation
- Population Constraints on Growth
- Urbanization - U.S.
- Age Distribution - U.S.

Environment:

- Contamination of Environment
- Oceans
- Land Abuse
- Toxic Substances
- Modification of Biosphere

Economics:

- Inflation
- Capital Shortages

Individual and Society:

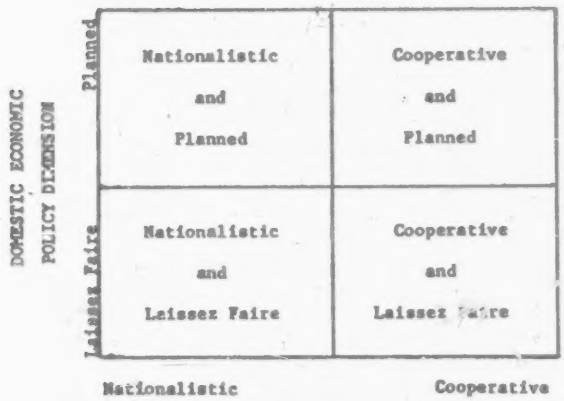
- Science/Technology Process
- Changing Concept of Equality
- Values
- Institutional Failure

2. Two Alternative Futures:

A frequently used approach to characterizing the future is that of scenario writing which has been defined as a "tool for creative thinking in preparing policy decisions."[5] Properly executed, it is not a forecast of the future, but a systematic way of combining technological, economic or political developments to obtain a feel for the long-range consequences. To illustrate the technique, and to provide alternative futures to which space flight planning might be referred, we have created two significantly different and self-consistent scenarios. The first step was to construct a "scenario map" (Figure 2), which graphically presents the major boundaries of the scenarios. Two major boundaries or continua were chosen as being the dominant descriptions of these futures.

FIGURE 2

A SCENARIO MAP



[5] Gerardin, L., "Study of Alternative Futures, A Scenario Writing Method," in a Guide to Practical Technological Forecasting, J. R. Bright and M. E. F. Schoeman, Editors, Prentice-Hall, Englewood Cliffs, N.J., 1973.

One boundary is the degree to which the *U. S. Government intervenes in domestic economic activities*. This ranges from one extreme of a laissez-faire economy to a totally planned and regulated economy. In the laissez-faire economy, the belief is that industrial activities, left to the forces of market supply and demand, can most efficiently and effectively provide the necessary goods and services to the society and that only this way can a high standard of living be attained. The planned economy is based on the premise that industry does what is best for industry, which may not coincide with the interests of society and the common good. Hence, the Government must actively and aggressively intervene to ensure that industry acts in accordance with proscribed societal standards.

The second dimension is the degree to which the U.S. participates in the solution of international problems. One extreme is the super nationalist chauvinism while the other extreme is total cooperation and leadership perhaps at the expense of domestic standards of living.

The four scenarios which result from these combinations are shown on the map and include:

nationalist - laissez faire
nationalist - planned
cooperative - laissez faire
cooperative - planned

For this exercise we have chosen to describe the nationalist - laissez faire and cooperative - planned scenarios. Many other dominant boundaries could have been chosen. It is difficult, of course, to determine the causal events of characteristics from which a societ evolves. We have chosen these boundaries because, to a very large extent, they embody just the kinds of choices that the nation is presently making.

The country is erratically moving upward (in the map) in the continuum describing U.S. intervention in the domestic economy. Recent actions such as the establishment of Amtrak, the Lockheed loan, efforts to assist Pan Am, the proposed Consumer Protection Agency, manipulation of the U.S. wheat market, wage and price controls, housing subsidies and Model Cities legislation emphasize this trend. At the same time, when efforts such as these do not immediately achieve their stated goals regardless of the reason, policy quickly moves in the other direction. Among these shifts are Postal Service reorganization, abolition of wage and price controls, revenue sharing, and abandonment of the "Great Society" legislation.

Overall, however, the trend over the past two decades has been towards *increased* government planning and intervention in the domestic economy. This is often thought of as a departure from traditional American philosophy and intent, but examination of U.S. economic history suggests that the dominance of government over industry is in fact a *return* to the original concepts of the Founding Fathers. The "robber baron" era was, in fact, an anomaly made possible by loopholes in several legislative changes. Fearful of potential corporate power, it was not until late in U.S. history that the corporate body could own land in its own right. Hence, the concept of the government manipulating the economy and dominating the productive forces for the common good is, contrary to folklore, a basic American tenet.

The path of the U.S. along the second continuum, the degree of international cooperation, has been much more circuitous. Clearly, the nation is not wearing the blinders of the isolationism so prevalent in the early part of the century. However, neither have humane considerations and cooperation become fundamental forces of foreign policy. This was dramatically evidenced

by the recent conditions of agricultural assistance to the starving nation of Bangladesh; in return for agricultural assistance the nation had to agree to forego the Cuban market for its only export — gunny sacks. Concomitantly, in real dollars, U.S. foreign aid has been decreasing, and as a percentage of total GNP, the U.S. allocates less to foreign aid than most other developed nations.

Economic policy has always been a tool of foreign policy — witness centuries of embargoes, tariff restrictions and the like. Recognizing the need for cooperative action in the face of resource shortages, grave international economic, pollution, famine and energy crises, the nation has yet to turn this recognition into any concerted action or policy plan. Nationalism is clearly not waning, and it is difficult to discern a conscious U.S. movement along this continuum.

The two boundaries for the scenarios were also chosen because they represent particularly sensitive issues for the acceptability of space missions. The space program, it can be argued, is necessary to maintain full employment, and this alone justifies substantial federal investment. The degree to which the federal government manipulates funding of the space program to achieve domestic goals may soon be a very real policy question.

Space missions can, of course, be used to satisfy international goals. In the 1960s, space activities were a dominant instrument of increasing U.S. prestige and world respect in the aftermath of the Cold War. Many of the international crises requiring international cooperative action — degradation of the biosphere, resource and energy shortages, famine, proliferation of nuclear weaponery — can all utilize different aspects of space capabilities.

The following scenarios are presented in summary form. The scenarios are self-consistent combinations of events depicting a likely world within the boundary definitions.

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SCENARIO A: NATIONALIST/LAISSEZ-FAIRE SCENARIO

Assumptions of the Scenario:

This scenario is based primarily on two basic assumptions:

> First, the U.S. government will rely more on industry for the maintenance of the economy. The market forces of supply and demand will determine the proper allocation of resources.
>
> Second, the U.S. government seeks to maintain the U.S. position as the most advanced nation in the world, both militarily and economically.

To avoid the danger of a distorted reality, it should be mentioned that the above set of government policies, if carried to the extremes, would find few supporters. Most people would agree that some government involvement in the domestic economy, and some involvement in international cooperation is valuable. However, many people believe there is too much government involvement already and that the proper balance must be reached. This scenario, then, attempts to point out some possible effects of a change from the present set of government policies towards a system of less government involvement. The fundamental attributes of this scenario are presented in Figure 3.

There are several present or potential situations that could trigger this form of policy change. First, the government has increasingly tried to manipulate the domestic economy to stabilize it, -- in terms of employment and production fluctuations and price stability, -- while still promoting a high rate of economic growth. The present situation of high inflation, high unemployment and declining "real" economic growth has certainly disenchanted many people with the government's economic policies. The stronger the measures taken by government (price controls), the more ineffective they seem to be (created shortages which increased inflation instead of curbing it).

FIGURE 3

IMPORTANT ATTRIBUTES: NATIONALIST/LAISSEZ-FAIRE SCENARIO

- Maintenance of many current institutions, i.e., nuclear family, religious institutions.
- Individual choice continues to be a social goal.
- High rate of economic growth.
- Profit motive is best method of resource allocation.
- Economic independence for U.S.
- Strong defense system is necessary to maintain the international balance of power.
- Self-achievement is still an important goal of most individuals.
- Technology is important for economic growth and increased well-being.
- Prefer local solutions, rather than federal intervention into social problems.
- Some reduction in civil rights is necessary for the benefit of society.
- Foreign aid continues to be tied to national goals.
- Continuation of ideological split between "East - West" powers.
- Relaxation of some environmental and consumer protection legislation to maintain a strong national economy.

Another government policy, its attempts to fight poverty, has also been viewed by many as an utter failure, for several different reasons. Many people resent supporting those who do not work. They perceive no real improvement in the poverty situation and do not wish to pay higher taxes for more ineffective programs, especially now with inflation so high and "real" incomes declining.

Also of concern to a great many people is the size of the federal government and the problem of "red tape". How can any organization so large and unwieldly be expected to operate effectively? Such an attitude creates popular pressure to limit the scope of government and to keep it more efficient, or at least maintain its functions in smaller, local units where there is knowledge and care for local problems.

Obviously it is unreasonable, given our present values and conditions, to assume that government involvement will, or should, dry up completely. What is generally called for is a re-ordering of priorities. Individuals must be responsible for themselves, the government cannot be. There are certain areas that government involvement is necessary for the survival of society.

Crime prevention is one of those areas. The rapid increase in crime and violence in the recent past, and the prospect for continued increases in the future are alarming. The costs of crime are borne by everyone in society through increased prices, insurance rates, fear, etc. (of course, the costs are higher for the victims), and most people do want to decrease crime prevention activities. In recent years, crime prevention has often stressed rehabilitation and changing the environmental influences of crime. To many people these methods have been complete failures; crime has increased and recidivism is

still high. This indicates a need for another policy change, a change to more stringent law enforcement.

If the political process is at all sensitive to the wishes of the people, and if the government is responsive and if the number of people with these views grows in the future, government involvement is likely to change in these directions.

In terms of international involvement, there are several conditions that will cause the United States to maintain a strong nationalist policy. For example, increased international competition has hurt many U.S. industries, causing the loss of many jobs. Many cooperative efforts benefit other countries more than the U.S., and sometimes involve sacrifices in the U.S. If the U.S. economy continues to suffer its present condition of economic doldrums, it is unlikely that many Americans will want to sacrifice their well-being for someone in another country. With jobs very difficult to find, few people are willing to give one up to foreign competition.

Another situation that is likely to increase the nationalism of U.S. foreign policies is the shortage of materials, including food and energy. Especially important is the likelihood of the formation of cartels to limit the supply and raise the price of essential materials, i.e., oil. The goals of resource independence and national security are likely to become more important, necessitating strong nationalist foreign policies to preserve our national well-being.

SCENARIO B: PLANNING/COOPERATION SCENARIO

Assumptions of the Scenario:

This scenario is based on two fundamental premises:

> the U. S. government actively intervenes in the U.S. economy to manipulate and direct the actions of the productive forces of the economy for the common good; and
>
> the U.S. government actively participates and cooperates with other nations and international organizations to assist in the solution of existing and prevention of potential international crises.

This scenario could logically develop from the present domestic and international troubles that the U.S. finds itself in. First, industry with some oversight and regulation by the U.S. government seems unable to sustain continued economic prosperity without severe economic fluctuations incorporating material shortages, insufficient supply and inadequate quality of goods and services, rampant inflation, and rising balance of payments deficits. At the same time, while the national economy is experiencing difficulty, many firms are enjoying excellent sales and history making profits. Hence, decision making becomes centralized in the federal government which increases its regulation and intervention to "guide" the performance of the economy along acceptable lines. This could include stringent, yet realistic, wage and price controls; allocation of existing supplies of scarce resources and stockpiling supplies for the future; government takeover of "true monopolies" such as utilities, transportation and communication firms; and institution of excess profits taxes and elimination of depletion allowances. The fundamental attributes of this scenario are illustrated in Figure 4.

At the same time great control would be exercised over the nature of the goods and services produced and the methods by which they could be produced and distributed. This would include stringently enforced quality

FIGURE 4

OTHER ATTRIBUTES: PLANNED/COOPERATIVE SCENARIO

- Tolerance of new and different lifestyles.
- Moderate economic growth.
- Rigid consumer and environmental legislation.
- No self-sufficiency in energy.
- Possible fear and distrust of U.S. as an international "do gooder".
- Increases in per capita real affluence.
- Food/Energy/Resource crisis present but considerably less severe.
- Active multi-country exploration and exploration of the oceans.
- Economic interdependence among developed nations and between underdeveloped and developed nations.
- Continued worldwide inflation.
- Decrease in use of military force and interdependency creates fear of using economic force.
- Recognition that social problems require institutional and political remedies rather than technological panaceas.
- Decrease in per capita domestic resource use and waste generated.

and safety regulations and standards for *all* products, rigid pollution abatement requirements without exception, consumer legislation governing the integrity of firm's conduct, provision for damages to the consumer as a result of industrial malfeasance, strict regulations governing occupational safety and protection of the employee.

Internationally, the U.S. would actively assist in solving and preventing international crises by contributing two of the nation's greatest strengths: its managerial and technical capability as well as substantial financial assistance. Individuals representing the nation's best would be "loaned" full time at federal expense to international organizations charged with attention to a given problem. International cooperation would include automatic large scale disaster relief; mutual interdependence for supplies of scarce resources, especially food and energy; U.S. medical, technical, and population planning assistance; and a forum with supralegal powers for resolution of conflict and monitoring of the proliferation of weaponery.

Concomitantly, the government would assume more and more responsibility for the individual and the scenario implies implementation of large scale social welfare programs. Among them would be income redistribution through a negative income tax, taxing of the super rich, and abolition of tax shelters; government financial insurance including medical and dental health care, retirement insurance; day care centers; food and housing allowances to offset inflationary trends (no household would have to pay in excess of 45% of their disposable income for minimum standards of food and housing); government subsidies to education, revitalization of the cities, medical health care and research, and so forth.

Individual behavior would be deregulated and there would be a great deal of choice among life styles, living arrangements and work relationships.

The Implications of this World:

What does this world mean? First, while economic growth will continue at moderate levels, it will be an inflationary world at the outset because of the large amounts of government spending. Over time, however, the inflationary aspects could be dampened through tax reform and income redistribution so that government programs could be financed through general revenues.

Secondly, the scenario implies that the institutions will be created that can effectively provide the necessary national and international mechanisms for the scenario events to occur. This is probably the weakest link of the scenario. The scenario implies threats to existing power bases such as industry leadership, political patronage, even individual national identity would be subservient to international liaisons and organizations. Because of the threats to existing power bases, it will be extremely difficult to move completely into this path. Institutional insufficiency is the major difficulty. Only through creation of effective and responsive bureaucracies can this scenario be successful.

Thirdly, the scenario also implies a great deal of individual freedom of action and choice. There are many incentives built into it *not* to join the labor force. This could have exceedingly disrupting implications not only in terms of inadequate supplies of available labor but also increasing demands for government services.

Finally, the world implies a great deal of support for space activities, both to ensure domestic full employment and to assist in international activities. It is likely that these efforts would be largely government-financed through government agencies rather than as sole ventures of private industry.

This world may be inherently unstable. The threats of inflation and the drains that the social welfare programs and international cooperation would entail may be too severe. The success and stability of this scenario would depend upon several factors:

- institutional reform and creation of an effective and responsive bureaucracy;
- income redistribution to prevent massive deficit financing and, hence, rampant inflation;
- adequate incentives to participate in the labor force;
- form for resolution of international conflict.

3. Forecasts and Assessments of Future Civilian Space Activities:

a) The Development of National Goals

At best, the concept of national goals is ambiguous, at worst controversial. There is no national consensus about priorities, no set of national goals neatly summarized in a document. Indeed, the great discussion about "re-ordering of national priorities" has made it clear that no consensus exists concerning national objectives and their integration in a set of ordered priorities. Only through analysis of actions by the Congress, the Executive branch of the government, the business community and the private consumer sector, can one discern a phantom set of national goals and priorities implied in those actions.

It has been argued[5] that national goals can be inferred from the level of expenditure allocated to a given area. The argument goes as follows.

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[5] Lecht, Leonard A., Changes in National Priorities During the 1960s: Their Implications for 1980, (National Planning Association, Washington, D.C.), 1972.
Lecht, Leonard A., Goals, Priorities and Dollars: The Next Decade (The Free Press: New York), 1966.

The allocation of the total efforts of the nation at any given point in time should indicate the momentary sense of priorities, and changes in allocations over a period of time should indicate changing trends in those priorities. The best available common denominator for the allocation of the nation's efforts is the dollar expenditure toward each of the phantom goals.

In the aggregate, U.S. dollar expenditures represent the blending of judgments on national priorities by government, business and private consumers. The government responds to perceived needs, and through debate and compromise, charts new directions and changes in priorities. The business community, labor unions and private consumers act on the basis of what they perceive to be in their best interests and their actions collectively are a measure of their current priorities with a discounted future interest.

Elements of national expenditures which comprise the Gross National Product (GNP) thus constitute one measure of priorities for the nation as a whole.

However, level of expenditures may more accurately reflect a condition of the *past*, rather than a statement about where the nation wishes to be. Using expenditure levels for 1969 and 1962 one can see (Figure 4) that there were shifts in the aggregate levels of expenditure, the relative ranking -- priorities, if you will, of the different categories did not shift dramatically.

In establishing a set of national goals, it is important to develop a quantifiable statement of where the nation wishes to be in each area so that progress to or away from that goal can be monitored. Dollar expenditures are often the *means* to achieve the goal, but in and of themselves do not

reflect a goal. Hence, in this task a great deal of effort was devoted to determining what the nation does wish to accomplish. This was done by reference to the existing goals, literature,[6] interviews and polling.

A list of the national goals obtained by this process is given in Figure 5. All national goals, of course, are not equal. Earlier efforts to determine priorities among competing goals were based on levels of expenditures of the past. In the effort here, we have asked the question: "In view of where we are today, to what activities should the nation's efforts be devoted?" Using a modified Delphi approach questioning a panel of experts and nonexperts, the relative weights and rankings shown in Figure 6 were determined. These weights were then used in the later matrix analysis. These weights, of course, are highly subjective and the public's view of them may change frequently and rapidly. For instance, the goal category "agriculture and food" was considerably higher in urgency due to recent concern with the world food supply. Any solution to this problem would undoubtedly lower the priority of that goal.

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[6] Albert H. Cantril and Charles Roll, Hopes and Fears of the American People (Universe Books: New York, 1971).

The "Quality of Life" Concept: A Potential New Tool for Division Makers (An Anthology of Selected Readings prepared by the Environmental Protection Agency) 1972.

The Economics of National Priorities, Hearings before the Subcommittee on Priorities and Economy in Government of the Joint Economic Committee, Congress of the U.S., 92nd Congress, First Session (June 1971).

Barry M. Blechman, E. M. Gramlich, and R. W. Hartman, Setting National Priorities: The 1975 Budget (Brookings Institution: Washington, D.C.) 1974.

Olaf Helmer, On the Future State of the Union, Report R-27 (Institute for the Future: Menlo Park, California), 1972.

FIGURE 5

EXPENDITURES FOR SOME GOAL AREAS
1962 Versus 1969
(Billions of 1969 Dollars)

Goal Area	Expenditures		Rank	
	1962	1969	1962	1969
Housing	37	35	8	9
Urban Facilities	47	59	2	6
National Defense	67	79	1	1
Social Welfare	46	71	3	2
Health	44	64	4	3-4
Education	42	64	5	3-4
Transportation	39	62	7	5
R&D	21	27	10	10
Natural Resources	7	10	11	11
Environment		6		12
Foreign Aid	6	5	12	13
Communication	22	37	9	8
Farm Product	40	51	6	7

b) Relationship Between Space Activities and National Goals

We drew up a list of possible space missions, functions, and activities (Figure 7) which might be conducted now or in the next two and one half decades. While an attempt was made to eliminate redundancies, no attempt was made to distinguish between new and innovative missions and missions which are currently being planned or studied.

It should be noted that the items in the list are not mutually exclusive. In some cases, a combination of items may be mutually supportive. For example, weather satellites can provide data for weather forecasting, and the weather forecasts could then be communicated to large numbers of individuals by broadcast satellites.

FIGURE 6

NATIONAL GOALS - A RANK ORDERING AND WEIGHTING

Goal	Rank	Weight
Agriculture and Food	1	8.4
Natural Resources and Material Supply	2	6.8
Housing	3	6.7
Environmental Quality & Pollution	4	6.5
Education	5	6.3
Jurisprudence	6-7	5.9
National Economy	6-7	5.9
Law and Order	8	5.6
Medicine & Health	9	5.4
Defense	10-11	4.8
International Cooperation	10-11	4.8
Social Interaction	12	4.3
Urban Design & Environment	13	4.2
Foreign Aid	14-16	3.4
Cultural Activities	14-16	3.4
Economics of the Individual	14-16	3.4
Transportation	17	2.9
Disaster Prediction and Control	18	2.6
Recreation and Leisure	19	2.4
Public Utilities	20	2.3
Communication	21	2.2
Maintenance of the Bureaucracy	22	1.6

We then carried out a cross support analysis of the identified space missions/functions/activities, and their contribution to national goals. The possible missions were treated both as independent variables and as dependent variables. That is, two kinds of cross support analyses were performed.

The first analysis was conducted by assigning numbers (representing judgments of the degree of cross support) in answer to the following questions: "Assuming this particular mission were conducted successfully, to what degree would its results support the achievement of the particular national goal?". Numbers were assigned according to the following scale:

1 = little or no support

2 = some support

4 = considerable, significant degree of support

8 = major support

Because of the difficulties which can arise with combining negative and positive numbers, no negative numbers were utilized.

The second analysis was conducted in a similar manner, representing a response to the following question: "Assuming the United States makes a commitment to this particular goal, to what degree will this commitment tend to support this particular space mission?". Numbers were assigned as in the first analysis.

The national goal areas previously defined were used in the cross support analyses.

c) Mission Support for Equally Weighted Goals:

The detailed results of the cross support analysis (matrix worksheets) are given in the September 28, 1974 report. Figure 7 summarizes the results

FIGURE 7

RANK ORDERING OF MISSIONS

(Assuming Goals are Equally Weighted)

	PANEL 1	PANEL 2
1.	Pollution Monitoring	Disaster Warning
2.	Resource Mapping/Monitoring	Weather, Climate Control
3.	Data Network	Resource Mapping/Monitoring
4.	Reflectors	Broadcast Satellite
5.	Broadcast Satellite	Data Network
6.	Weather, Climate Control	Common Carrier
7.	Disaster Warning	Meteorological
8.	Meteorological	Multiple Access
9.	Atmospheric Physics	Navigation/Traffic Control
10.	International Missions	Aerodynamic Research
11.	Multiple Access	Hazardous Material
12.	Navigation/Traffic Control	Pollution Monitoring
13.	Data Commercialization	Satellite Servicing
14.	Common Carrier	Aircraft Noise Reduction
15.	Colonization	Reflectors
16.	Aircraft Noise Reduction	Orbiting Power Station
17.	Hazardous Material Tracking	Private Communications Satellite
18.	Orbiting Power Station	Atmospheric Physics
19.	Ionospheric Physics	International Mission
20.	Defense System Monitoring	Health Treatment
21.	Manufacturing	Data Commercialization
22.	Aerodynamics Research	High Energy Physics
23.	High Energy Physics	Defense System Monitoring
24.	Private Communications Satellite	Solar, Other Measurements
25.	Waste Disposal	Ionospheric Physics
26.	Health Treatment	Waste Disposal
27.	Electromagnetic and Particle Experiments	Electromagnetic and Particle Experiments
28.	Intra-solar System Probes	Paired Probes
29.	Astronomy	Assembly
30.	Paired Probes	Colonization
31.	Extra-solar System Probes	Manufacturing
32.	Satellite Servicing	Meteor Analysis
33.	Extraterrestrial Communication	Astronomy
34.	Solar, Other Measurements	Intra-solar System Probes
35.	Meteor Analysis	Extraterrestrial Communication
36.	Assembly	Extra-solar System Probes

by rank ordering the missions according to the total support each provides for the national goals.

Although there are differences in the two independent rankings, considerable agreement exists. For example, four of the top six missions are common to both rankings.

- weather, climate control
- resource mapping/monitoring
- data network
- broadcast satellite

Out of the top one-third (12) missions, the two rankings list eight common missions. In addition to the above four, these include:

- disaster warning
- meteorological satellites
- multiple access communications satellites
- navigation/traffic control

The differences in rankings may be attributed to one or a combination of the following factors: unintentional biases based on perceived feasibility, differences in perceived opportunities and in future values, and different judgments as to the strengths of perceived impacts.

d) Relationship Between Weighted Goals and Missions:

The mission to goal analysis to this point has assumed that all national goals have the same weight. If we add the dimension of differences in priorities among the goals, as shown earlier in Figure 6, we find that space missions are able to substantially contribute, in theory, to the achievement of some of the highest priority goals. The Figure 8 below indicates that environmental quality and agriculture and food receive the greatest contribution from space missions.

FIGURE 8

NATIONAL GOALS RECEIVING SUPPORT FROM CIVILIAN SPACE MISSIONS

Goal	Total Space Contribution
Agriculture and Food	2368.8
Natural Environment	2132.0
Natural Resource and Material Supply	1768.0
Urban Environment	1699.2
Health and Medicine	1609.2

When consideration is made of the priorities among the goals, the rank orderings of the missions are somewhat different than those rankings which assumed equal weights. The highest ranking missions are:

- Pollution monitoring
- Resource Mapping/Monitoring
- Data Network
- Broadcast Communications

4. Prospective Crises: Some Challenges to Planning

This section describes another dimension of planning for the future; i.e., the understanding of potential future crises which might face the U.S. over the next decades, and an examination of the relative importances of these crises in terms of their impacts on society. The crisis orientation is an important point of departure in creative thinking about the future because it is the nature of our society to respond to crises.

For example, in describing our time to a visitor from the past, we would almost certainly include the energy crisis, the Middle East crisis, the Watergate crisis, and the inflationary crisis in our list of descriptors of the present. Without focusing on potential crises, as depressing as that might be, our descriptions of the future would be totally inadequate; more importantly, little would be known of the immediate need for creative and decisive policy-making. We talk of crises, of unpleasant futures, to prompt policy analysis and policy-making where it may count the most.

Inevitably, this approach presents arguments which will be discouraging. If the projection of crises are believable, the import will be one of Gotterdammerung. But the future is not likely to be as dismal as these essays might indicate for several reasons:

- The crises are plausible but not necessarily probable.
- The consequences, as mentioned above, may be seen in a different perspective than we think.
- We have focused only on crises not, their opposite. (For reasons which are not very clear, it is easier to visualize odious situations than desirable states).
- As the probability of a crisis increases, it is more likely that action will be taken in an attempt to avert the evolving situation.
- Some of the crises discussed here are apparently casually connected; correction of one may mitigate others.

Yet running throughout the discussion is the suggestion that the coming twenty-five years is indeed a time of climax, a time of issues of unprecedented magnitude and permanence. Food shortages, materials and energy availability, and monetary instability: all of these issues have affected society before; what is new is their potential simultaneity and world scope. Certainly within these crises, and their concomitant consequences, are the seeds of the future.

Important changes of the next two and a half decades seem likely to come not only from science and technology, from the waxing and waning of institutions responding to external pressures and internal decay, from policies of Governments and the values and actions of groups of people, but from the unexpected and deleterious actions of the socio/economic/political system. These unexpected system responses can trigger crises.

"Crisis" can have several definitions; the meaning employed in this essay is:

> A crucial situation; a situation whose outcome decides whether possible bad consequences will follow.

Thus, this section on future crises deals with potential situations which may have grievous consequences. At least two degrees of uncertainty are involved in each crisis: the inevitability of the crisis itself and the likelihood that the anticipated consequences will flow from the crisis situation. With respect to the former uncertainty, each crisis is defined in terms of trends already well-established, which, through their coincidence and reinforcement make the crisis, if not likely, at least plausible. The second uncertainty, that of the consequences of the crisis, is more difficult. Society has a marvelous propensity to adapt, and situations which seem onerous and threatening to us may, to some future society, seem part of the natural order and a desirable state of affairs. For example, a chronic energy shortage is perceived by many economists as a potential cause of inflation, recession and perhaps economic depression. Yet this image assumes a continuation of current lifestyles; it is possible that society, faced with high energy costs, will change to lifestyles requiring lower energy inputs. Thus the crisis, energy shortage, may have occurred, but its consequences will be viewed with quite a different feeling in retrospect than

some view it prospectively. There is no alternative, however, to using current values in projecting crisis.

It is one thing to suggest that recognizing key future crises can form an interesting forecasting model; it's quite another to develop a metric for selecting a subset of issues to address. John Platt, in his paper "What We Must Do," suggested as an index of crisis intensity, a measure which included the number of people likely to be affected, the degree of this effect, and the time until the effect is realized. In his scaling, a grade 1 crisis represented total annihilation; a grade 2 crisis, great destruction or physical, biological, or political change; a grade 3 crisis, almost unbearable world tension, and so on.[7]

Recent work in technology assessment has added other criteria to Platt's list. One might include "relative confidence" or certainty in the degree of effect of the crisis. For example, a potential crisis which is very uncertain and yet which could have a tremendous effect might be accorded a very high priority. The list might include "reversibility" (that is, the ability for any policy to reverse the consequences of the crisis -- an irreversible crisis is much worse than a reversible one). Finally, "responsibility" could be an important priority-ordering criterion: does the responsibility for curing the crisis lie clearly within some existing institution's mission? The responsibility criterion also becomes important when more than one institution thinks it has the job of correcting a problem, because more often than not, jurisdictional disputes will arise that can inhibit clear-cut and decisive action.

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[7] John Platt, "What We Must Do," Science, Vol. 166, No. 3909 (November 28, 1969), pp. 1115-1121.

Thus the dimensions by which the severity of a future crisis might be judged (although these criteria are clearly not of equal weight) include:

1. Number of people affected.
2. Degree of effect.
3. Probability of timing of the impact.
4. Reversibility.
5. Responsibility.
6. Confidence in judgments.

A most important crisis would be one in which a large number of people are likely to be severely affected, almost immediately, in an irreversible way, with no institution clearly having responsibility for detecting or curing the problem. This situation would obtain at either of two levels of confidence: great certainty in the judgments, or great uncertainty.

What then are some of the issues which meet these criteria? While others could certainly extend this list considerably, our nominations for the top set are shown in Figure 9.

We made an attempt to understand the relationships among the crises on this selected list, using the cross-impact matrix technique.

Figure 10 is a cross-impact matrix of crises discussed in this section. As in the case of all cross-impact matrices, this figure shows the relationships which appear to exist among the variables considered. The seven postulated crises appear on both the ordinate and abscissa. The numbers in the cells of the matrix are in answer to the question:

> If the crisis shown in the ordinate occurs, how will the crisis, shown in the abscissa, be effected?

FIGURE 9

SOME IMPORTANT CRISES

CRISIS	CRITERIA					
	NUMBER OF PEOPLE AFFECTED	SEVERITY OF THE EFFECT	PROBABILITY	REVERSIBILITY OF THE COURSE OF DEVELOPMENT OF THE CRISIS	RESPONSIBILITY	CONFIDENCE IN JUDGMENT
Nuclear war	Very Large	Very Great	Very Low	Possible	Diffuse	Moderate
Severe food shortages	Very Large	Very Great	High	Possible	Diffuse	High
Deterioration of the biosphere	Very Large	Moderate-Great	Moderate	Difficult	Diffuse	Low
Imbalances in the distribution of wealth	Very Large	Great	Very High	Very Difficult	None	Moderate
Shortages of mineral resources	Large	Moderate-Great	Very High	Very Difficult	None	High
Energy shortages	Moderate-Great	Moderate-Great	Very High	Very Difficult	Diffuse	High
Inflation and monetary instability	Moderate-Great	Moderate-Great	Very High	Very Difficult	None	Moderate

FIGURE 10

CROSS-IMPACTS AMONG CRISES — OCCURRENCE

IF THESE OCCUR ⇩ / THESE ARE AFFECTED AS SHOWN IN THE MATRIX ⇨	Nuclear War	Food Shortages	Deterioration of the Biosphere	Imbalances in the Distribution of Wealth	Shortages of Mineral Resources	Energy Shortages	Inflation, Capital Shortages
Nuclear War		-4	+4	?	?	?	-2
Food Shortages	+2		+4	+4	0	+2	+2
Deterioration of the Biosphere	0	+2		0	+1	+1	+2
Imbalance in the Distribution of Wealth	+2	+1	0		+3	+3	+3
Shortages of Mineral Resources	+2	+1	+1	-2		+2	+2
Energy Shortages	+2	+3	+2	-2	0		+3
Inflation, Capital Shortages	+1	+2	0	+2	+2	+2	

Key: +4 = Greatly intensified
0 = No effect
-4 = Greatly mitigated
? = Uncertain

A +4 indicates a judgment that the dependent crises will be greatly intensified. a -4 indicates the judgment that the dependent crisis will be greatly mitigated.

The preponderance of + signs in the matrix indicates that by and large the occurrence of any of the crises seems likely to intensify the crises which have not yet been realized. More specifically:

- All of the crises lead in the direction of war, and except for war itself, in the direction of inflation and capital shortages.
- Imbalance in the distribution of wealth seem likely to be intensified by food shortages, inflation and capital shortages, but are mitigated by shortages of mineral resources and energy shortages, particularly if energy supplies and mineral resources are owned by currently impoverished countries.

Figure 11 shows the other side of the coin. In this cross-impact matrix, it is assumed that the crises are corrected and the matrix displays the consequences of these corrections. For example, the numbers contained in the cells of the matrix answer the question:

> If the crisis shown in the ordinate were to be prevented, how would the other crises be affected?

In this case, the matrix shows a preponderance of minus signs, showing that correction of the crises generally leads to improvement in other areas as well. However, the intensities contained in this matrix as compared with the previous matrix shows that the situation is probably non-linear; that is, the occurrence of one crisis seems more likely to trigger other crises than the curing of one crisis is likely to cure other crises. For example, eliminating the possibility of nuclear war probably has little affect on any of the other crises except food shortages which may be intensified.

FIGURE 11

CRG IMPACTS AMONG CRISES — NONOCCURRENCE

IF THESE DO NOT OCCUR ⇩ / THESE ARE AFFECTED AS SHOWN IN THE MATRIX ⇨	Nuclear War	Food Shortages	Deterioration of the Biosphere	Imbalances in the Distribution of Wealth	Shortages of Mineral Resources	Energy Shortages	Inflation, Capital Shortages
Nuclear War		+2	0	0	0	0	0
Food Shortages	+1		-3	-4	0	-1	-1
Deterioration of the Biosphere	0	0		0	0	0	-2
Imbalance in the Distribution of Wealth	-2	-4	-1		-1	-1	?
Shortages of Mineral Resources	-1	0	0	+2		0	-3
Energy Shortages	-1	-2	-3	+2	-3		-3
Inflation, Capital Shortages	-1	0	0	-1	0	0	

Key: +4 = Greatly intensified
0 = No effect
-4 = Greatly mitigated
? = Uncertain

Curing of deterioration of the biosphere seems to be ineffective in all other areas except inflation and capital shortages which it will help (since the need for spending for anti-pollution devices will be diminished). Cross impacts of specific note include:

- Curing of imbalances in the distribution of wealth will greatly mitigate food shortages since developing countries would be able to purchase agricultural inputs and food; in other words; the free market system could be brought into play to help avoid starvation.

- Energy shortages reduce the intensity of deterioration of the biosphere since freely available energy could be used to clean the environment.

- Similar abundant energy can be substituted in many instances for short raw materials; therefore the availability of energy mitigates the potential mineral resource crisis.

Anticipating crises, understanding their nature to the degree possible, and moving to implement policies which mitigate them, would seem to be an important thrust for the political sciences in the next two decades. We need, following the suggestion of John Platt, a metric for crises; and following the suggestion of Hal Linstone, a system of crisis discounting akin to cash flow discounting which could help sort out priorities for the nation.

The dimensions of these and other potential crises are discussed in the next section which constitutes the bulk of this report since the Study Group decided that its approach to characterizing the future would be based on the examination of certain Trends and Issues facing the nation.

5. Conclusions

There is no doubt that the next twenty-five years will be a period of crisis and challenge. The principle components of the "problematique" and the idea that the world is in the midst of a major transition in its historic

developmental patterns are familiar to almost everyone. The contents of this report, particularly the essays on Trends and Issues, have provided some measures of the dimensions of the problems, food, population, warfare, energy, pollution, etc. and their intense interactions. The core issue may well be stated as *the maintenance of an equitable and dynamic equilibrium between world population and world resources.* This issue is not new; Malthus advanced it, albeit pessimistically, at the beginning of the 19th century. What is new, in addition to the exponentially growth of the crises, is the profound changes in the world's *perceptions of equity and social justice,* which would require, if pursued, a redistribution of the wealth and basic changes in the rules of the "system". It is not reasonable to expect that a system in which "the rich get richer and the poor get poorer" will survive without the imposition of imperialism on the international scene and a paternal fascism in domestic affairs.

The alternatives are the challenges that face the nation and the world.

It became clear to us during the course of this study on the Outlook for Space that space flight with its global perspective, its ability to tie nations and peoples together, and its unique capabilities to illuminate man's universe and his nature has an enormous, untapped potential for contributing to the solutions of the world's problems and to meeting its needs.

With tools such as space flight, mankind has the means to make the difficult transition into the twentieth century. He needs only the will and determination.

SPECIAL ANALYSIS K

RESEARCH AND DEVELOPMENT

This analysis covers the funding of research and development across all departments and agencies with R&D programs of $10 million or more, representing over 99% of total Federal funds for R&D. It consists of two sections. The first highlights the R&D policies and trends in the 1984 budget. The second describes in more detail the R&D programs of 13 agencies whose R&D obligations individually exceed $150 million.

Part I. Highlights

Total Federal funding for research and development, including R&D facilities, is proposed at $47.0 billion in 1984, an increase of $6.9 billion or 17% above the 1983 level of $40.1 billion. Included within the overall R&D funding is support for the conduct of basic research, estimated to increase by 10%, from $6.0 billion in 1983 to $6.6 billion in 1984, including an 18% increase in programs of the National Science Foundation.

The Federal Government funds R&D activities to serve two broad purposes:

- To meet specific Federal Government needs—where the principal user of the R&D is the Government itself—for example, to ensure a strong national defense;
- To meet broad national needs—where the Federal Government supports R&D that the private sector lacks incentive to invest in adequately, in the national interest—to help assure the strength of the economy and the quality of life for all people. Included in this category are, for example, agricultural and health research; support of basic research through programs of the National Science Foundation and the general science programs of the current Department of Energy; and the pursuit of selected long-term energy technologies, such as magnetic fusion.

The 1984 budget continues to reflect the established policies of the Administration in funding R&D but further strengthens support in areas of major Federal responsibility. It provides for:

- Major increases across all R&D programs of the Department of Defense;
- A significant increase in Government-wide support of basic research with emphasis on support of research in the physical

Reproduced from Special analyses, budget of the United States Government, fiscal year 1984. Washington, G.P.O., 1984. p. K1-K28.

sciences and engineering. Advances in these fields are key to future national defense and the long term competitiveness of the U.S. economy, particularly in high technology industries.

- A number of major new initiatives, particularly in energy-related programs, currently in the Department of Energy, and in NASA that will significantly enhance the research productivity of the Nation's scientific community especially in basic research. These include a new center for materials research at the Lawrence Berkeley Laboratory, expansion of the National Synchrotron Light Source at Brookhaven National Laboratory, a new colliding beam facility at the Stanford Linear Accelerator Center, and a numerical aerodynamic simulation capability at NASA's Ames Research Laboratory.
- Continued reductions in Federal support of nearer-term R&D and demonstration programs (e.g., in energy technologies). For such programs the private sector, not the Federal Government, has the expertise and capability to select and fund the advancement of technologies that can be successfully brought into the marketplace. To complement private sector efforts, the Federal Government's role is primarily to create an economic climate conducive to private investments, through such measures as tax incentives and reductions in the burden of regulations. Federal Government investments should be limited to longer term research and technology support which the private sector does not have the economic incentive to provide for adequately to serve the national interest.

The Administration will further seek, in 1984, to make more effective use of increased research funds, particularly in the basic sciences to:

- Attract the highest caliber scientists and engineers, particularly young faculty members, into research and encourage and support them in their careers. These efforts will assist in ensuring a high quality scientific workforce to meet needs of the Nation both in the near and the long term;
- Encourage greater and more creative interaction among university, Government and industry scientists to bring the Nation's best scientific expertise together in addressing the most challenging scientific and technical problems and opportunities; and
- Upgrade the scientific instrumentation of universities to enhance productivity and excellence in research and the training of scientists and engineers.

The 1984 budget also includes proposed efforts by the NSF and the Department of Education to improve the teaching of science and mathematics in the Nation's secondary schools. Though not covered in this analysis, these efforts will help in improving the

capability of the future work force to contribute to economic growth in an increasingly technological society.

Total obligations and outlays for the conduct of all Federal R&D programs and for related facilities are shown in Table K-1.

TABLE K-1. TOTAL FEDERAL FUNDING FOR CONDUCT OF R&D AND RELATED FACILITIES

(In billions of dollars)

	Obligations			Outlays		
	1982 actual	1983 estimate	1984 estimate	1982 actual	1983 estimate	1984 estimate
Conduct of R&D	36.4	38.9	45.8	34.5	37.7	42.7
R&D Facilities	1.2	1.2	1.2	1.3	1.2	1.1
Total	**37.6**	**40.1**	**47.0**	**35.8**	**38.9**	**43.8**

CONDUCT OF RESEARCH AND DEVELOPMENT

The 1984 budget includes $45.8 billion in obligations for the conduct of R&D, an increase of $6.9 billion or 18% over 1983. Highlights of the programs of the major R&D agencies that account for 93% of the proposed obligations for the conduct of R&D by all agencies are presented below:

- **Department of Defense (DOD).**—Obligations for the conduct of R&D by DOD are estimated at $29.9 billion in 1984, an increase of $6.7 billion or about 29% above 1983. This represents 65% of the total Federal funds for R&D proposed for 1984. The increased funds are proposed for R&D largely related to advanced strategic systems such as the Peacemaker and Trident II ballistic missiles. In addition, the Department would also provide for increased emphasis on basic research in such areas as materials and microelectronics, and advanced technology development in such areas as very high speed integrated circuits.
- **National Aeronautics and Space Administration (NASA).**—Obligations for the conduct of R&D by NASA are estimated at $2.5 billion in 1984, about equal to 1983. The 1984 request would allow NASA to pursue a vigorous program of space science, applications, and advanced technology for space projects and future aircraft. The 1984 budget proposes several new initiatives such as a Venus Radar Mapper to provide a map of the surface of Venus, a numerical aerodynamic simulation capability, and development of advanced composites for large aircraft structures. Previously approved projects such as the Space Telescope, and the Advanced Communications Technology Satellite (ACTS) will be continued.

- **Energy Related Activities.**[1]—Obligations for the conduct of R&D programs currently in the Department of Energy are estimated at $4.7 billion, about the same as in 1983. However, basic research funding would be increased by $160 million, or more than 18% over 1983. Increases are proposed to strengthen the nuclear weapons R&D program, to enhance support for long-term energy research, and to maintain a strong national basic science effort in high energy and nuclear physics. These increases are offset by proposed reductions in support for nearer-term energy technologies such as fossil and solar demonstrations, where reliance is placed on private sector support.
- **Department of Health and Human Services (HHS).**—Obligations for the conduct of R&D in HHS are proposed for an increase of $100 million, from $4.3 billion in 1983 to $4.4 billion in 1984. This represents a 12% increase over the two year period, 1982-1984. The National Institutes of Health (NIH) account for about 87% of total R&D funding by HHS. An increase of $71 million above 1983 is proposed for R&D programs of NIH, including basic research in the biomedical sciences.
- **National Science Foundation (NSF).**—R&D obligations by NSF are expected to increase by $180 million, or 17%—to $1.2 billion in 1984. The additional funds will largely be devoted to strenthening support of basic research in the mathematical and physical sciences and engineering, that support long-term economic growth. This increase also provides additional funds for upgrading research instrumentation at universities.

Table K-2 summarizes Federal support for the conduct of R&D by agency.

CONDUCT OF BASIC RESEARCH

The 1984 budget continues to reflect the Administration's view that investments in basic research across all scientific disciplines are critical to the long-term economic strength of the Nation and the well-being of its citizens. Basic research in such fields as mathematics, physics, chemistry, and engineering provides the foundation, in the long term, for a strong national defense, and leads to new discoveries and new technologies and industries that enhance U.S. competitiveness, employment and the quality of life.

Federal Government funding for the conduct of basic research is included within the total support for the conduct of R&D. In 1984, obligations for the conduct of basic research are estimated at $6.6 billion, an increase of $594 million or 10% above the 1983 level.

[1] These programs, along with other activities currently funded by the Department of Energy, will be proposed for reassignment to other Executive departments and agencies.

TABLE K-2. CONDUCT OF RESEARCH AND DEVELOPMENT BY MAJOR DEPARTMENTS AND AGENCIES

(In millions of dollars)

Department or agency	Obligations			Outlays		
	1982 actual	1983 estimate	1984 estimate	1982 actual	1983 estimate	1984 estimate
Defense-Military Functions	20,576	23,179	29,882	18,201	21,847	26,844
Energy Related Activities	4,758	4,712	4,713	4,974	5,012	4,911
Health and Human Services	3,935	4,316	4,416	3,978	4,262	4,339
(National Institutes of Health)	(3,432)	(3,771)	(3,842)	(3,438)	(3,737)	(3,808)
National Aeronautics and Space Administration	3,084	2,506	2,473	3,220	2,386	2,421
National Science Foundation	975	1,060	1,240	1,014	1,002	1,137
Agriculture	798	850	849	808	839	848
Transportation	309	393	519	349	376	451
Interior	381	373	329	392	411	348
Commerce	290	312	227	285	315	249
Environmental Protection Agency	335	241	208	336	295	250
Nuclear Regulatory Commission	221	210	200	209	210	200
Veterans Administration	140	165	163	138	157	156
Agency for International Development	165	152	161	179	200	152
All other [1]	388	391	418	426	425	433
Total	**36,354**	**38,860**	**45,796**	**34,509**	**37,735**	**42,741**

[1] Includes the Departments of Education, Justice, Labor, Housing and Urban Development and Treasury, the Tennessee Valley Authority, the Smithsonian Institution, the Corps of Engineers, and the Federal Emergency Management Agency.

This increase will result in a "real" growth in the Government-wide support of basic research of more than 4% above 1983.

For agencies primarily supporting basic reasearch in the physical and engineering sciences, particularly DOD, NASA, NSF, and including the energy-related programs currently under DOE, the increase in 1984 will be 15% over 1983.

Support for basic research in the life sciences, particularly in NIH, has been growing significantly in recent years. The Administration is seeking, through emphasis on the physical and engineering sciences in the 1984 budget, to balance Federal support of basic research across all major disciplines.

Enhanced support of basic research will further strengthen the scientific capability of the Nation's universities whose researchers receive about half of the total Federal obligations for basic research and conduct about half of all basic research performed in the Nation.

Table K-3 summarizes Federal support for the conduct of basic research by agency.

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Table K–3. CONDUCT OF BASIC RESEARCH BY MAJOR DEPARTMENTS AND AGENCIES

(In millions of dollars) [1]

Department or agency	Obligations			Outlays		
	1982 actual	1983 estimate	1984 estimate	1982 actual	1983 estimate	1984 estimate
Agencies supporting primarily physical sciences and engineering: [2]						
National Science Foundation	916	998	1,181	954	943	1,083
Energy Related Activities	777	861	1,021	774	859	1,001
Defense—Military Functions	686	769	867	603	746	776
National Aeronautics and Space Administration	538	605	682	537	588	658
Interior	74	88	89	74	89	94
Commerce	17	18	16	16	16	17
Other Agencies [3]	9	7	8	9	7	8
Subtotal	3,017	3,347	3,864	2,967	3,249	3,636
Agencies supporting primarily life and other sciences: [4]						
Health and Human Services	1,953	2,184	2,238	1,962	2,154	2,214
(National Institutes of Health)	(1,840)	(2,049)	(2,086)	(1,835)	(2,022)	(2,068)
Agriculture	331	362	381	338	356	380
Smithsonian Institution	55	60	68	47	60	62
Environmental Protection Agency	33	21	17	30	25	22
Veterans Administration	13	15	15	13	15	15
Education	16	16	14	22	22	18
Other Agencies [5]	22	22	22	22	23	13
Subtotal	2,422	2,678	2,755	2,434	2,655	2,723
Total	5,439	6,025	6,619	5,401	5,904	6,359

[1] Amounts reported in this table are included in totals for conduct of R&D.
[2] Includes mathematics and computer sciences.
[3] Includes the Corps of Engineers, the Federal Emergency Management Agency, the Tennessee Valley Authority, and the Department of Transportation.
[4] Includes psychology and social sciences.
[5] Includes the Departments of Labor, Justice, and Treasury, and the Agency for International Development.

R&D FACILITIES

Excellence in research and development requires the availability of modern facilities and equipment. Additional funding for research equipment and instrumentation is included in support for the conduct of R&D including basic research. Funds identified separately by Federal departments and agencies for R&D facilities are summarized in Table K–4.

Obligations for R&D facilities, which include primarily construction or renovation of general purpose laboratories and research support facilities, would decrease by $54 million, to $1,195 million in 1984.

Trends in the funding of R&D facilities generally reflect program directions in agency support for the conduct of R&D as described below.

Table K-4. RESEARCH AND DEVELOPMENT FACILITIES BY MAJOR DEPARTMENTS AND AGENCIES

(In millions of dollars)

Department or agency	Obligations			Outlays		
	1982 actual	1983 estimate	1984 estimate	1982 actual	1983 estimate	1984 estimate
Energy Related Activities	762	619	501	804	623	532
Defense—Military Functions	290	323	438	232	289	349
National Aeronautics and Space Administration	92	160	156	109	136	129
Health and Human Services	29	60	29	38	31	35
(National Institutes of Health)	(20)	(21)	(26)	(35)	(20)	(20)
Agriculture	30	38	26	30	45	22
All other [1]	30	49	45	40	34	48
Total	**1,234**	**1,249**	**1,195**	**1,253**	**1,158**	**1,114**

[1] Includes the Departments of Transportation, Commerce, Interior, and Treasury, the Agency for International Development, Veterans Administration, Tennessee Valley Authority, Smithsonian Institution and the National Science Foundation.

Part II. Agency R&D Programs

Presented below are summaries of the R&D activities of the 13 agencies whose R&D obligations individually exceed $150 million.

DEPARTMENT OF DEFENSE

The Defense R&D program is oriented toward the development of strategic and tactical weapons and supporting systems to provide for the Nation's defense. DOD obligations for the conduct of R&D in 1984 would total $29.9 billion, an increase of $6.7 billion over 1983. Within the total, funding for basic research would increase by $98 million to $867 million in 1984. R&D facilities funding would total $438 million, up from $323 million in 1983. Major R&D efforts by DOD mission category in 1984 include:

Technology Base and Advanced Technology Development.—The purpose of these programs is to investigate promising new technologies and to avoid technological surprise by potential adversaries. The Very High Speed Integrated Circuits program will continue to push for further miniaturization of microelectronic devices. Increased attention also will be paid to human factors in the Defense mission. Protection against chemical agents, aids for use in training of personnel and exploration of the relation between man and machine will be stressed. Other areas of focus include information processing, materials research, fault-resistant electronics and advanced computer languages.

Strategic Programs.—In addition to the Peacekeeper and Trident II efforts, continued emphasis will be given to ballistic missile defense, an advanced technology bomber and an anti-satellite system. The communications and control systems that are needed for these and existing systems will also receive increased emphasis.

Tactical Programs.—Systems are under development that will improve the capability of U.S. general purpose and theater nuclear forces, and allow the rapid deployment of those forces wherever the vital interests of the U.S. are threatened.

- The Army is continuing work on upgrades to the M-1 tank and Bradley Fighting Vehicle System and is increasing its efforts on remotely piloted vehicles and some areas of air defense.
- The Air Force is developing a deep strike interdiction version of an existing fighter aircraft, a more reliable fighter engine, an air-to-air missile and a new trainer aircraft for undergraduate pilot training.
- The Navy is developing a lightweight anti-submarine torpedo, a new longer range anti-submarine missile and a new destroyer. Upgrades to current subsystems to improve detection, tracking and targeting will also increase the capability of major systems now in production.

Intelligence and Communications, Program Management and Support.—R&D on intelligence and communication systems will focus on communication satellites, on radios that will work in the electronic noise of the battlefield, and on surveillance radars. Work will also continue on the use of technology to reduce manufacturing costs and to extend the life and capability of existing defense systems.

Table K-5. **DEPARTMENT OF DEFENSE—MILITARY RESEARCH AND DEVELOPMENT**

(In millions of dollars)

Type of activity	1982 actual	1983 estimate	1984 estimate
OBLIGATIONS			
Conduct of R&D:			
Research, development, test and evaluation:			
Technology base	2,945	3,137	3,555
Advanced technology development	750	826	1,211
Strategic programs	4,846	5,747	8,978
Tactical programs	6,750	7,222	8,705
Intelligence and communications	2,104	2,686	3,474
Program management and support	2,538	2,869	3,236
Other appropriations	642	692	722
Total conduct of R&D	20,576	23,179	29,882
Total conduct of basic research, included above	(686)	(769)	(867)
R&D facilities	290	323	438
Total obligations	**20,866**	**23,502**	**30,320**
OUTLAYS			
Conduct of R&D	18,201	21,847	26,844
R&D facilities	232	289	349
Total outlays	**18,432**	**22,136**	**27,194**

NATO Cooperation.—Cooperation in research and development and joint production of new weapon systems will be pursued to make the best use of Alliance resources. Funding for these activities is not identified separately in Table K-5 but is included in the other categories listed in that table.

Table K-5 provides the details of the Department of Defense military R&D funding.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Through the programs of NASA, the Federal Government develops and operates the Shuttle based Space Transportation System and makes investments in R&D that yield other new space technologies to improve the national security and the long term scientific and technological strength of the Nation. NASA programs also provide new knowledge about the Earth, the solar system, and the universe.

Now that the Space Shuttle is in its operational phase, it is no longer appropriate to classify all of NASA programs as R&D. Therefore, the amounts shown for 1982, 1983, and 1984 for NASA R&D exclude funding for Shuttle production and operation, tracking and data acquisition activities, and related institutional support.

In 1984, R&D obligations for the agency will decrease slightly due to spending patterns on previously initiated projects, although new obligational authority for R&D activities is projected to increase by $44 million. Basic research obligations by NASA in 1984 would amount to $682 million, an increase of $77 million over 1983. Obligations for construction of R&D facilities in 1984 would total $156 million.

Space Transportation.—With the initiation of Space Shuttle operations in November 1982, the major R&D phase of the Shuttle program has been concluded. A fully operational and cost effective Shuttle is essential to exploit space effectively and to help maintain U.S. leadership in space throughout this century.

Space Transportation R&D activities provided by the 1984 budget include Shuttle modifications and improvements and continued development of two versions of the Centaur upper stage—a new high energy upper stage for use with the Shuttle. Also included will be a tethered satellite program to extend the use of the Shuttle to conduct scientific experiments in the boundary region between space and the Earth's upper atmosphere. The tethered satellite will be an international cooperative program with the Italian government.

Space Science.—In this area, spacecraft in flight are conducting deep space astronomical observations from Earth orbit or exploring the solar system.

- The High Energy Astronomy Observatory (HEAO), launched in 1979, will continue operations and data analysis activities.
- Two Voyager spacecraft, launched in 1977, have successfully encountered Jupiter and Saturn, and Voyager 2 will continue on its way to Uranus for an encounter in 1986.
- The flight of several other smaller scientific satellites (e.g., International Ultraviolet Explorer) will be continued.

The 1984 budget supports continuation of the flight of these satellites in space and the analysis of scientific data sent back to Earth. It also provides for the retrieval and repair in orbit of the partially disabled Solar Maximum Mission Satellite.

The proposed budget continues development of major flight projects to be launched in the future.

- The Space Telescope is planned for launch in 1985 and will serve as a major astronomy facility for a 15- to 20-year period.
- The Gamma Ray Observatory is planned for launch in 1988 and will enhance basic research in high energy astrophysics, providing new knowledge about objects in deep space.
- Spacelab astronomy experiments, designed for repeated use, will be conducted on the Shuttle to improve our understanding of the Sun and the universe.
- Work is continuing on the Galileo mission to Jupiter; the spacecraft is composed of two segments—an orbiter and a probe to enter the upper atmosphere of Jupiter. The Galileo orbiter and probe will be launched in 1986 and will arrive at Jupiter in 1988 to carry out long-term studies of the planet, its satellites, and its magnetosphere.

In 1984, funds are also proposed to initiate the Venus Radar mapper project, for a 1988 launch, to map the planet. A new Explorer class project for research in ultraviolet astronomy will also be initiated, recognizing the potential of lower cost missions to conduct important science experiments in space.

Space and Terrestrial Applications.—The 1984 budget continues to support research that could lead to the broad application of space technology to national needs. The 1984 budget proposes continued funding for space-related research activities to:

- Improve understanding of Earth resources, climate, weather, and pollution;
- Advance knowledge in materials science and materials processing through low gravity experiments in space;
- Extend the capability for satellite communications to higher frequencies than those employed with current satellites;

The 1984 budget reduction for Space and Terrestrial Applications reflects decreasing obligations in two major projects that are nearing completion, Landsat and the Earth Radiation Budget Experiment (ERBE). However, the budget also includes increasing obligations for an Advanced Communications Technology Satellite (ACTS), while funding for other continuing programs will be maintained at about the same level as in 1983.

Landsat D, the fourth in the series of experimental Earth observing satellites, was launched successfully in July 1982 and is performing satisfactorily. A follow-on satellite will be completed in 1984, ready to succeed Landsat D when needed. Space remote-sensing technology, such as that employed by Landsat D, has the potential to improve our ability to manage critical Earth resources.

The ERBE satellite will be launched by the Shuttle in 1984. The program is designed to provide global measurements of the level of solar and cosmic radiation absorbed by the Earth and also map levels of ozone and other aerosols in the stratosphere. Such observation will help improve our understanding of the factors that determine the Earth's climate.

TABLE K-6. **NATIONAL AERONAUTICS AND SPACE ADMINISTRATION—RESEARCH AND DEVELOPMENT**

(In millions of dollars)

Type of activity	1982 actual	1983 estimate	1984 estimate
OBLIGATIONS			
Conduct of R&D:			
Space transportation systems	890	117	183
Space science	582	752	779
Space and terrestrial applications	319	398	289
Aeronautical research and technology	258	313	300
Space research and technology	118	131	138
Tracking and data acquisition	12	8	22
Research and program management	905	787	762
Total conduct of R&D	3,084	2,506	2,473
Total conduct of basic research, included above	(538)	(605)	(682)
R&D facilities	92	160	156
Total obligations	**3,176**	**2,666**	**2,629**
OUTLAYS			
Conduct of R&D	3,220	2,386	2,421
R&D facilities	109	136	129
Total outlays	**3,329**	**2,522**	**2,550**

The development of the ACTS will be a joint venture of government and industry and will provide advanced, higher frequency, satellite communications technology for use later in the decade.

Aeronautical Research and Technology.—The 1984 budget includes funds for a significant enhancement in new obligational

authority for research in fundamental aeronautical disciplines such as fluid and thermal physics, materials and structures, and propulsion. In addition, technology development at the concept, technique or component level would also be enhanced. Planned obligations for aeronautical R&D will decrease slightly in 1984 because of the extraordinary rate of obligations against prior year authority experienced in 1983. New budgetary authority would increase from $280 million in 1983 to $300 million in 1984.

Funds are included for initiating in 1984, the development of a numerical aerodynamic simulation capability which will further the state-of-the-art of aerodynamic research and design and will also be an important tool for research in areas such as climate modeling and computational chemistry.

The 1984 budget also provides for research and technology development related to the use of composite materials in large aircraft structures. These lightweight materials would result in longer-range and more efficient military and civil aircraft.

Agency-wide support activities.—Obligations for agency-wide support activities would remain at about the 1983 level. These programs include primarily NASA civil service and administrative costs supporting R&D activities, construction and maintenance of the agency's R&D facilities, and R&D addressing fundamental space technology problems and opportunities common to a wide spectrum of space programs.

Table K–6 provides the details of NASA's R&D funding.

ENERGY RELATED ACTIVITIES

Energy related R&D, currently supported by the Department of Energy, covers a broad range of activities: a ***National Defense Program*** related to the development and testing of nuclear weapons: a ***General Science Program*** of basic research in high energy physics and nuclear sciences; and an ***Energy Program*** focused on long-term R&D. Table K–7 provides summary information on the funding of these programs.

Obligations for the conduct of energy related R&D (including facilities) are estimated to total $5.2 billion in 1984, a decrease of $117 million from 1983. Obligations in 1984 for R&D facilities, including the construction or upgrading of laboratories and other research support facilities, will amount to $501 million.

Obligations for the conduct of basic research, included in the total for the conduct of R&D, are estimated to be slightly over $1 billion in 1984. This represents an increase of $160 million, or more than 18% over the 1983 level. Within the basic research total, $82 million would be provided to initiate a number of major new projects in both the Energy Program and the General Science Pro-

gram, that will significantly improve the Nation's capacity for basic research at the frontiers of science. These include:

- initiation of a national advanced materials research center at the Lawrence Berkeley Laboratory to improve the linkages among academic, national laboratory, and industry scientists for the future advancement of high technology industries;
- expansion of the National Synchrotron Light Source at Brookhaven National Laboratory to meet the growing need of industry, national laboratories, and universities for this research tool;
- building on a rapid time scale, a linear colliding beam accelerator at the Stanford Linear Accelerator Center to demonstrate the feasibility of new techniques for very high energy electron-positron collisions;
- upgrading of on-campus Van de Graaff accelerators at the University of Washington and Yale University to maintain the performance capabilities of two essential components of the university based nuclear physics research program; and
- a $6 million university instrumentation procurement program to provide large state-of-the-art equipment used in energy-related research areas.

Highlights of the Energy related R&D activities by major programs are provided below:

The ***National Defense Program*** primarily supports the continued development and testing of nuclear weapons. It also supports the development of improved technologies for monitoring nuclear weapons treaties and of improved methods for safeguarding nuclear materials. In addition R&D efforts will continue in developing methods for the safe storage and disposal of radioactive wastes resulting from weapons production, and research on improved propulsion reactors for naval vessels. Obligations for the National Defense Program for the conduct of R&D will increase from $1.7 billion in 1983 to $1.9 billion in 1984. Funds for R&D facilities in 1984 include construction of the Waste Isolation Plant (WIPP) in New Mexico for R&D on disposal of nuclear waste. Conduct of R&D increases provide funds for staff additions to strengthen the national weapons laboratories, for increased weapons tests, and for increased research in the basic physics of nuclear weapons.

The ***General Science Program*** supports research in high energy and nuclear physics. An increase of $90 million, to $643 million in 1984, for the conduct of basic research will continue support for advanced accelerator concepts as well as for theoretical efforts to understand the basic constituents of matter and energy and the forces that govern their interaction. Because of the exceptional research opportunities in high energy physics and the demonstrated excellence of the U.S. program, the Administration is committed

to maintaining a strong national effort in this field. The 1984 budget request would provide for (a) increased utilization of existing accelerator facilities, (b) operation of the newly completed (1983) Energy Saver Superconducting Synchroton at Fermilab in the 500–1,000 GeV energy range, and (c) continuation of the construction at Fermilab of the Tevatron I and II projects which will provide increased proton-fixed target and proton-antiproton colliding beam capabilities. Funds will also be provided for upgrading accelerators at Yale University and the University of Washington and for initiation of the Stanford Linear Collider (SLC).

The ***Energy Program*** is focused in 1984 on long-term R&D to complement industry investments in new or improved energy technologies. It supports basic and generic research to enhance the scientific base for future advances in these technologies and continues support for the development of selected technologies of a high risk but potentially high payoff nature, such as magnetic fusion, where significant private investment is unlikely. In addition, the Energy Program includes research on the environmental and human health effects of energy production technologies. Energy Program obligations for the conduct of R&D would decrease from $2.4 billion in 1983 to $2.2 billion in 1984, largely reflecting net savings from proposed reductions in non-nuclear technology development and demonstration activities. Obligations for R&D facilities in this area would be $152 million, a reduction of $84 million, paralleling the reduction in the conduct of R&D.

In the *basic energy sciences,* funding for the conduct of R&D and related facilities will increase by $67 million to $350 million in 1984 for research in such fields as nuclear science, chemistry, engineering, materials science, mathematics, biology, and geoscience. This program provides the fundamental scientific and technical base for future advances in technology development. In addition, it provides support for the operation of several unique national facilities such as the National Synchrotron Light Source (NSLS) at the Brookhaven National Laboratory, the High Voltage Electron Microscope at Lawrence Berkeley Laboratory (LBL), and the Electromagnetic Isotope Separation Plant (calutrons) at Oak Ridge National Laboratory. In 1984 a national materials research center at LBL and an upgrade of the NSLS facility will be initiated.

The 1984 budget will continue the redirection of the non-nuclear R&D programs to limit federal support to long-term generic research and place greater reliance on the private sector for support of nearer-term technology development. Obligations for the conduct of R&D in the *fossil, solar* and *conservation* programs are expected to be $302 million in 1984, a decrease of $405 million from 1983.

Funding for the conduct of *fossil* related R&D and associated facilities would be $138 million in 1984, a decrease of $234 million.

The 1984 budget is focused on research to strengthen the technical base for future fossil technology development. Support would continue to be provided in such areas as the chemistry of coal conversion, environmental controls, combustion research, and the understanding of the behavior of oil and gas reservoirs.

Research in support of *solar* energy, proposed at a level of $87 million, will emphasize materials development for a variety of applications and continue to support research in the areas of solar thermal, photovoltaics, biomass, and wind conversion. In 1983, work on the international SOLERAS agreement will be completed. Research to foster energy *conservation* will be focused on improved understanding of energy losses in building systems, research on alternative heat engines, and development of advanced technologies for electrical systems and energy storage. Technology demonstrations in industrial, transportation, and buildings and community systems conservation will be scaled down in 1984. Conduct of R&D for energy *conservation* in 1984 would be $84 million.

The 1984 budget provides for a broad program of research in fission and fusion energy sources R&D. In the *magnetic fusion* program, funding of $467 million for the conduct of R&D and associated facilities would enable the continuation of investigations, at about the 1983 program level, of key physics issues involved with confined plasmas and further research on superconducting magnets, high power radiofrequency electronics, advanced materials development, and mathematical computer modeling needed for fusion technology development.

Within the fission effort the *breeder reactor* program will be funded at $603 million in 1984, maintaining a priority for the design and construction of the Clinch River Breeder Reactor (CRBR). In addition, long-range research will continue in support of breeder technology. Total funding for the conduct of breeder R&D will increase by $62 million over 1983. Other nuclear fission research areas such as *nuclear fuel cycle, converter reactors systems, and advanced nuclear systems* are funded for conduct of R&D and associated facilities at a level of $129 million for 1984.

Additional funds are proposed for nuclear safety and *commercial nuclear waste* management research. For example, in cooperation with the Nuclear Regulatory Commission, technical investigations associated with the disabled Three Mile Island nuclear power reactor will be supported. The fission R&D program will also seek to resolve technical issues associated with the construction of a permanent repository for nuclear waste. Obligations for these activities in 1984 will total $69 million.

Finally, the Energy Program supports R&D to determine the biological and environmental effects of energy production and use. The *biological and environmental research* R&D emphasizes the

health effects of radiation, the use of radiation in medical diagnosis and therapy, and generic biological research related to radiation and other cellular traumas. The level of obligation for such activities will be $158 million in 1984. This effort also supports research to determine the relationship between the CO_2 content of the atmosphere and the earth's climate changes. Funding in 1984 for CO_2 studies will total $12 million.

Table K-7. ENERGY RELATED ACTIVITIES [1]

(In millions of dollars)

Type of activity	1982 actual	1983 estimate	1984 estimate
OBLIGATIONS			
Conduct of R&D:			
National defense program	1,526	1,727	1,905
General science program	500	553	643
Energy program	2,731	2,432	2,165
Total conduct of R&D	4,758	4,712	4,713
Total conduct of basic research, included above	(777)	(861)	(1,021)
R&D facilities	762	619	501
Total obligations	**5,519**	**5,331**	**5,214**
OUTLAYS			
Conduct of R&D	4,974	5,012	4,911
R&D facilities	804	623	532
Total outlays	**5,778**	**5,635**	**5,443**

[1] These programs, currently supported by the Department of Energy, will be proposed for reassignment to other Executive departments and agencies.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

The Department of Health and Human Services (HHS) obligations in 1984 for the conduct of R&D would increase by $100 million over the 1983 level to a total of $4.4 billion. Within this total, funding for basic research is estimated to be $2.2 billion. Obligations for R&D facilities would total $29 million in 1984. This represents a decline from the $60 million provided in 1983. The higher level of obligations in 1983 was primarily due to the nonrecurring costs for a single large project—construction of the new research headquarters for the Food and Drug Administration.

Health.—Over 87% of the Department's funds for the conduct of R&D and over 93% of the Department's basic research funds would be obligated by the National Institutes of Health (NIH) for biomedical research to advance the Nation's capabilities for the prevention, diagnosis, and treatment of disease. Several other agencies within the Department—the Alcohol, Drug Abuse, and Mental Health Administration, the Food and Drug Administration, the Centers for Disease Control, the Health Resources and Services

Administration, the Health Care Financing Administration, and the Office of the Assistant Secretary for Health—also support R&D programs in health related research.

The *National Institutes of Health (NIH)* consist of 11 separate Institutes which would obligate $3.8 billion in 1984 for the conduct of R&D, an increase of $71 million above the 1983 level; over one-half or $2.1 billion of NIH's total 1984 R&D budget would support basic research. Among the most significant activities to be supported by NIH are:

- Basic research on cancer chemoprevention including studies of nutritional factors; rehabilitation of patients with chronic obstructive pulmonary disease; prevention of glaucoma; diagnostic imaging, and the biological response to mixtures of chemicals;
- Clinical research where the emphasis is on intervention, including prototype development and refinement of products, techniques, processes, methods, and practices;
- Expansion of cooperative clinical trials on the acquired immunodeficiency syndrome/Kaposi Sarcoma problems; isolated systolic hypertension in the elderly; herpes simplex virus vaccine; and antiviral drugs against neonatal herpes, herpes encephalitis, herpes genitalis; the efficacy of interferon for controlling the frequency and severity of multiple sclerosis; gonococcal vaccines and the prevention of premature labor and the role of folic acid in neural tube defects; and
- Greater emphasis on basic clinical research into the cause, cure, and prevention of diabetes.

The *Alcohol, Drug Abuse and Mental Health Administration (ADAMHA)* conducts studies on the causes, prevention and treatment of alcohol and drug abuse and mental disease and neurological disorders, with emphasis on improving knowledge of effective prevention of these public health problems.

The 1984 budget proposes increases in levels for extramural research programs in biomedical, behaviorial and clinical areas. Obligations for ADAMHA would increase in 1984 to $314 million, an increase of $36 million over 1983.

Specific research areas would address:

- Neurosciences, behavioral sciences, psychopharmacology, and clinical investigations and evaluations of services to the mentally ill, with special emphasis on preventing and diagnosing mental and emotional problems in children;
- Drug abuse among the Nation's youth, including studies on the adverse health hazards of marihuana and cocaine; and
- Causes and consequences of alcohol abuse, particularly among teenagers.

The *Food and Drug Administration (FDA)* supports research relevant to its mission of regulating food, drugs, and biological and radiological products. In 1984, obligations for these activities are estimated at $82 million.

The *Centers for Disease Control (CDC)* supports studies on the epidemiology and control of communicable diseases and on health promotion and disease prevention. In 1984, obligations for these activities are estimated at $75 million.

Other Health Related Agencies within HHS would support research in areas such as how socioeconomic facts affect social security programs and the economy; survey methods and techniques for analysis of health statistics; and the organization, delivery, and financing of health services. This support will be provided through programs of the Health Resources and Services Administration, the Office of the Assistant Secretary for Health and the Health Care Financing Administration.

Human Services.—The Department's obligations for R&D in human services programs in 1984 would be $53 million, $11 million below 1983. The proposed 1984 budget would support a variety of developmental and social service research aimed at improving the Head Start program; the quality of life for the elderly; knowledge of child abuse and neglect; day care systems; family and community support systems and fostering independence for the disabled.

Table K-8 provides the details of the R&D funding of the Department of Health and Human Services.

NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) supports primarily basic research in all scientific disciplines through grants to scientists and engineers in academic institutions. NSF programs serve to advance scientific knowledge. Foundation support is particularly important because it complements the basic research programs of other agencies and assists in balancing Federal support for promising research across all fields of science and engineering.

The 1984 NSF budget includes $1.2 billion in obligations for the conduct of R&D, an increase of $180 million or 17 percent above 1983. This would provide a growth of about 12 percent in addition to cost increases due to inflation. Within this increase, support for the conduct of basic research would increase by about 18 percent. Specifically, the 1984 budget would:

- Provide special emphasis on disciplines such as mathematics, materials science, astronomy, and electrical, computer, and chemical engineering. Research in these disciplines has the potential to make important contributions to the long term

Table K-8. DEPARTMENT OF HEALTH AND HUMAN SERVICES—RESEARCH AND DEVELOPMENT

(In millions of dollars)

Type of activity and organizational units	1982 actual	1983 estimate	1984 estimate
OBLIGATIONS			
Conduct of R&D:			
Health:			
National Institutes of Health	3,432	3,771	3,842
Alcohol, Drug Abuse, and Mental Health Administration	243	278	314
Food and Drug Administration	73	77	82
Centers for Disease Control	75	70	75
Health Resources and Services Administration	12	10	1
Health Care Financing Administration	29	30	30
Office of the Assistant Secretary for Health	16	16	18
Subtotal, Health	3,879	4,252	4,362
Human Services:			
Office of Human Development Services	26	23	11
Social Security Administration	17	26	31
Departmental Management	13	15	11
Subtotal, Human Services	56	64	53
Total conduct of R&D	3,935	4,316	4,416
Total conduct of basic research, included above	(1,953)	(2,184)	(2,238)
R&D facilities	29	60	29
Total obligations	**3,964**	**4,376**	**4,444**
OUTLAYS			
Conduct of R&D	3,978	4,262	4,339
R&D facilities	38	31	35
Total outlays	**4,015**	**4,292**	**4,374**

competitiveness of the U.S. economy, particularly in high technology dependent industries.

- Provide $180 million in 1984, an increase of 61% over 1983, for upgrading research instrumentation primarily at universities. This sharp increase is included within the support for the conduct of basic research. Along with funds provided for this purpose in other agencies, the increase in the NSF budget would enhance research productivity by helping to alleviate the problem of growing obsolescence of research instrumentation at universities. It would also help ensure that future scientists and engineers are trained in the use of modern research instrumentation and techniques.
- Fund the continuation of the deep sea drilling project to provide scientific geologic information related to the Earth's crust, ocean sediments, geochemistry and paleontology.

In addition, the 1984 budget proposes increased funding in the U.S. Antarctic program for improvement of logistic support. These improvements are critical to the conduct of a safe and effective

research program and to the maintenance of an active and influential U.S presence in Antarctica.

DEPARTMENT OF AGRICULTURE

The Department of Agriculture supports research and development in several disciplines related to agriculture and forestry.

Obligations of the Department for the conduct of research and development are estimated to total $849 million in 1984, a decrease of $1 million from 1983. Of the total, $381 million would support basic research, an increase of $19 million over the 1983 expected obligations of $362 million.

The Department's 1984 budget is highlighted below by major bureau:

The Agricultural Research Service (ARS) would obligate $458 million for research designed to produce new knowledge and technologies required to assure the continuing vitality of the Nation's food and agriculture enterprise. This represents an increase of $12 million over 1983.

In 1984, increased emphasis would be placed on genetic engineering in the plant and animal sciences, human nutrition research, and improved post-harvest technologies. In addition, a new program of post-doctoral fellowships in ARS laboratories would be initiated. Short term applied research and development would continue to receive reduced Federal effort, since such activities are more appropriately financed by the private sector.

The Cooperative State Research Service would obligate $222 million to maintain support of the cooperative program with institutions in 50 States, the District of Columbia, Puerto Rico, Guam, the Virgin Islands, American Samoa and Micronesia engaged in research in agriculture, forestry, veterinary medicine, and the rural home and the community. Also, the budget would continue the competitive grants program in basic research important to increasing the efficiency of food production and improving human nutrition. For the first time, competitive grants for research in the animal sciences would be made.

The Forest Service would obligate $101 million, a decrease of $4 million from 1983, to provide knowledge needed to manage and protect forest and related rangeland resources to gain maximum economic and social benefits from their use. Research would be conducted on: genetics; silviculture and timber management; watershed management; wildlife, range and fish habitats; protection for forest resources from fire and forest pests; surface environment and mining; forest engineering and utilization; and economics of forest commodity production, processing and distribution.

In addition, $68 million would be obligated in other departmental programs for economic research, international cooperation and de-

velopment, transportation of commodities, nutrition information, and statistical reporting.

DEPARTMENT OF COMMERCE

The Department of Commerce has responsibility for ocean science and engineering research, meteorological research and forecasting, and for maintaining measurement standards. The 1984 budget would continue these programs in the National Oceanic and Atmospheric Administration (NOAA), the National Bureau of Standards (NBS), and other areas of the Department.

Obligations for the conduct of R&D by the Department in 1984 are estimated at $227 million, a decrease of $86 million from 1983. This decrease applies largely to relatively nearer term applied research and development, more appropriately the responsibility of the private sector.

National Oceanic and Atmospheric Administration (NOAA).—NOAA would continue R&D programs to develop systems and components for nautical and aeronautical mapping and charting; ocean engineering systems in support of NOAA ocean research and operational programs; better ways to conserve, protect, and manage the Nation's fishery resources; new and improved fishing equipment to protect endangered and/or threatened species; and timely and accurate meteorological, hydrologic, and oceanographic forecasting, detecting and tracking systems for protection of life and property. Obligations for the conduct of R&D by NOAA in 1984 would decrease from $194 million to $135 million. This reduction reflects decreases in applied areas, more appropriately supported by the private sector.

National Bureau of Standards (NBS).—R&D efforts for NBS are aimed at developing and maintaining a system of measurement required to support the Nation's industrial and scientific endeavors.

In 1984, NBS is expected to obligate $78 million for the conduct of R&D. This represents a $16 million decrease from 1983. Funding for the following programs would be terminated or reduced on the grounds that such research can and should be supported by the private sector: fire science and engineering ($6 million), building research ($3 million), ADP standards ($6 million), and recycled oil ($1 million).

Other Commerce R&D Activities.—Funding for smaller research and development programs in the Department of Commerce, which include those in the Bureau of the Census, the Patent and Trademark Office, and the National Telecommunications and Information Administration, would be $14 million in 1984.

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DEPARTMENT OF THE INTERIOR

The R&D activities of the Department of the Interior derive from its broad-ranging responsibilities for management of the Nation's natural resources, including developing energy and mineral resources, restoring and preserving wildlife habitats and wilderness areas, and improving the quality of our water resources.

Obligations for the conduct of R&D for the Department of the Interior for 1984 are estimated at $329 million. This represents a decrease of approximately $44 million from the 1983 level, primarily in applied mining and applied geological research.

Almost 90% of the Department's 1984 funds for the conduct of R&D would be obligated by the Geological Survey ($136 million), Fish and Wildlife Service ($89 million), and Bureau of Mines ($68 million). Highlights of the 1984 research objectives of these and other departmental programs are described below.

The *Geological Survey* undertakes research on the extent, distribution, and character of the Nation's natural resources and on the geologic processes, structures, and hazards that affect the development and use of the land and physical environment. Research priorities in 1984 would include continued development of:

- Accurate appraisals of land and mineral resources;
- New and improved methods of mineral exploration;
- An improved scientific basis for investigation and measurement of water resources; and
- Basic data on geologic principles and processes.

The *Fish and Wildlife Service* supports research performed in the Service's laboratories and field stations, and through cooperative efforts with State fish and game departments. It also provides Federal aid to States for research on restoration of fish and wildlife resources. This research provides basic biological information about species numbers, population dynamics, ecological relationships, and habitat requirements. In 1984, the Service would support research activities concerned with:

- The habitat of waterfowl, migratory birds, mammals and nonmigratory birds;
- Endangered and threatened species status, distribution and threats;
- Impact of broad-scale environmental changes on fish and wildlife populations and habitat; and
- Fish husbandry and aquaculture.

The *Bureau of Mines* conducts basic and applied research across the minerals cycle to improve our understanding of the principles of mining and minerals processing, and to reduce associated health hazards. Reductions are proposed in applied research, particularly in projects of a commercial nature which are more appropriate for the private sector to support. Basic research is proposed to increase

by 22% through reallocations of funds from applied research projects. The 1984 budget reflects an increased emphasis on strategic and critical minerals R&D activities and would stress:

- Long-range, high-risk research in extractive metallurgy technology that may result in new processing methods;
- Development of domestic source substitutes for imported strategic and critical minerals;
- Health-related research on the proper quality and quantity of air flow in underground mines; and
- Longer-term, generic research on fire and explosion prevention, methane and underground control, industrial hazards, post-disaster survival and rescue, explosives, and systems engineering.

Other Departmental Programs would provide for:

- Development of technology to generate additional water supplies by cloud seeding techniques; and
- Development of new materials, planning tools, design and construction techniques to solve problems arising in the development and operation of water resources projects.

DEPARTMENT OF TRANSPORTATION

The Department of Transportation's R&D program is oriented toward providing the information and new technology needed for its own operational (e.g., air traffic control) programs and for regulatory (e.g., automotive and aircraft safety standards) programs. Obligations for the conduct of research and development by the Department are estimated at $519 million for 1984, an increase of $126 million over 1983. The Department's 1984 budget for R&D, with explanations of major changes from 1983, is highlighted below by agency.

The Federal Aviation Administration would obligate $304 million in 1984. The proposed 1984 R&D obligations for FAA represent an increase over 1983 of $161 million. A major portion of this increase occurs in the advanced computer, aviation weather, communications and systems programs. This increase would allow greater emphasis on engineering work to enhance the safety and efficiency of the national air traffic control system, and on emerging technology to improve collision avoidance systems and enroute and terminal air traffic control systems.

The National Highway Traffic Safety Administration would obligate $57 million for motor vehicle research, traffic safety research and demonstrations emphasizing safety belt usage, alcohol counter measures, and for analytical studies. In 1984, a small increase is planned for highway safety research in support of the safety belt program. The National Accident Sampling System which provides

for the collection and analysis of nationally representative accident and injury data would be continued.

The Urban Mass Transportation Administration would obligate $46 million to assist in the development of improved mass transportation systems, equipment and procedures. Emphasis would be placed on research aimed at improving the operation and maintenance of existing transit systems.

The Federal Highway Administration would obligate $49 million to continue research programs in highway planning, design, construction, and maintenance to insure an effective and efficient highway system. Research would also be conducted in identifying, and correcting impediments to highway safety and on improving truck safety.

The Federal Railroad Administration would obligate $17 million to continue highest priority safety research. This would result in more cost-effective safety compliance and enforcement techniques.

The Maritime Administration would obligate $13 million to improve the productivity and competitive posture of the U.S. maritime industries. This level is $4 million below the 1983 budget.

The U.S. Coast Guard would obligate $22 million to support research to maintain and improve search and rescue systems, environmental protection, marine safety, aids to navigation, and the enforcement of laws and treaties, and activities affecting all Coast Guard missions. The proposed 1984 figure represents an increase of $2 million above the 1983 level.

The Research and Special Programs Administration would obligate $5 million to support emergency preparedness and mobilization, hazardous materials and pipeline safety regulatory programs, and long range university research.

The Office of the Secretary would obligate $7 million for broad-based policy research on domestic and international transportation issues of importance to the Nation.

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA) conducts research and development in support of the Agency's regulatory and enforcement missions. For 1984, EPA's R&D program will focus on three major concerns: (1) better linkage of research to the Agency's regulatory priorities; (2) greater attention to quality assurance to improve the reliability of scientific data used in Agency decisions; and (3) restructuring the Agency's long-range basic research program.

Total obligations for EPA's R&D program in 1984 are proposed to be $208 million, a decrease of 14% from 1983. This reduction reflects completion of major research to support regulatory decisions

and reductions for development of pollution control technologies. EPA's major research activities are highlighted below.

The acid rain/energy research program will be increased to understand better the phenomena of acid deposition. Specifically, a comprehensive atmospheric field study will be initiated, dry deposition monitoring will be accelerated, and watershed research studies will be expanded. Research in support of the Limestone Injection Multistage Burner (LIMB) control technology will be continued.

The hazardous waste research program will support efforts on land disposal of hazardous waste, post-closure monitoring of land disposal facilities, screening protocols for hazardous wastes, and research support for permitting hazardous waste disposal facilities.

The Superfund research program will maintain its research efforts at 1983 levels. However, funding will shift from engineering activities to monitoring and environmental effects research which are closely associated with current field work at hazardous waste sites. Funds for this research program are derived from the Hazardous Substance Response Trust Fund which is funded primarily by a tax on oil and chemical industries.

The drinking water research program will strengthen risk assessments, health research, and monitoring for the Drinking Water Program. Resources for groundwater transport and fate research are maintained at 1983 levels. Work will continue on revising the Primary Drinking Water regulations.

The air research program will continue the development of comprehensive health risk assessments for hazardous air pollutants, improve monitoring methods for sampling and analyzing non-criteria organic pollutants and improve air quality dispersion models.

The water quality research program will emphasize research on ocean dumping and water-quality based pollution control requirements. In the municipal wastewater area, research will focus on innovative and alternative wastewater treatment technologies and more efficient sludge management techniques. Industrial wastewater research will be reduced reflecting completion of the effluent guidelines effort and will be refocused to support the waste water permitting program.

The toxic substances research program will increase development of health risk assessment models. Total research funding is slightly lower in 1984 reflecting the completion of a major monitoring study and completion of engineering technical support for the review of chemicals.

The interdisciplinary research program will continue to support the Agency's research centers, long-term research grants, and development of economic benefits methods.

NUCLEAR REGULATORY COMMISSION

The Nuclear Regulatory Commission (NRC) performs research in civil uses of nuclear materials and facilities consistent with public health and safety, environmental quality, and national security. A major share of NRC's effort is devoted to research connected with the use of nuclear energy to generate electric power. Its research objective is to provide safety and analytical methods for assuring the quality of NRC's licensing procedures and regulatory work.

In 1984, NRC's obligations for the conduct of R&D are expected to decrease from $210 to $200 million. This reduction from 1983 is due primarily to the transfer of work at the Loss of Fluid Test Facility (LOFT) to an international consortium. Key areas, such as accident evaluation and mitigation and systems reliability analysis will be strengthened. In addition, reactor safety research, principally on the Clinch River Fast Breeder Reactor, will be continued.

VETERANS ADMINISTRATION

The Veterans Administration (VA) conducts and administers medical, rehabilitation, and health services research. In 1984 this agency would obligate $163 million, for the conduct of R&D.

The VA *intramural biomedical research program* is designed to benefit patients through increased quality and effectiveness of health care delivery. Priorities for 1984 include special research on Agent Orange, alcoholism, aging, and post-traumatic stress.

In *rehabilitation research,* the VA focuses on problems in the field of prosthetics, orthotics, wheelchairs, spinal cord injury and sensory aides for improving the care and rehabilitation of disabled veterans, including amputees, paraplegics and the blind.

The *health services research program* supports projects at VA facilities to improve the effectiveness, economy, and accessibility of health care services. In addition, emphasis will be placed on research relevant to health care delivery to veterans and the services provided to them.

AGENCY FOR INTERNATIONAL DEVELOPMENT

Research and development activities of the Agency for International Development (AID) consist mainly of applied research to solve specific problems associated with basic human needs and social and economic research aimed at improving U.S. and host country understanding of the barriers to development.

Obligations of AID for the conduct of R&D are estimated at $161 million in 1984, an increase of $9 million over 1983.

Programs under AID reflect the administration's recognition of the importance of R&D in addressing the problems faced by the Third World.

The majority of AID's 1984 R&D funds will be devoted to three critical problems: food production, with an emphasis on affecting developing country efforts to overcome the growing food crisis; population growth, emphasizing methods of controlling increasing population growth rates in the developing countries; and energy supply, emphasizing renewable and nonconventional energy sources critical for development to proceed.

OTHER AGENCY PROGRAMS

An additional 9 departments and agencies (listed in table K-2, footnote 1) would obligate an estimated $418 million in 1984, for the conduct of R&D, an increase of $27 million over the 1983 total. Obligations by these agencies amount to less than 1% of all federally funded programs in R&D. The programs of these agencies, like those of other agencies discussed above, are closely related to the agencies' missions.

Among the agencies in this category that expect to increase their obligations for R&D in 1984 are the Smithsonian Institution, Housing and Urban Development, the Federal Emergency Management Agency, the Tennessee Valley Authority, and the Departments of Justice, Labor, and Treasury.

SUPPLEMENTARY INFORMATION

Table K-9 provides information on the long-term trends in Federal funding for the conduct of R&D.

TABLE K–9. TRENDS IN CONDUCT OF R&D

(Obligations in billions of dollars)

Year	Defense [1]	All other	Total
1953	2.8	.3	3.1
1954	2.5	.3	2.9
1955	2.2	.4	2.5
1956	2.5	.5	3.0
1957	3.3	.6	3.9
1958	3.8	.8	4.6
1959	5.6	1.1	6.7
1960	6.1	1.5	7.6
1961	7.0	2.1	9.1
1962	7.2	3.1	10.3
1963	7.8	4.7	12.5
1964	7.8	6.4	14.2
1965	7.3	7.3	14.6
1966	7.5	7.8	15.3
1967	8.6	7.9	16.5
1968	8.3	7.6	15.9
1969	8.4	7.2	15.6
1970	8.0	7.3	15.3
1971	8.1	7.4	15.5
1972	8.9	7.6	16.5
1973	9.0	7.8	16.8
1974	9.0	8.4	17.4
1975	9.7	9.3	19.0
1976	10.4	10.4	20.8
1977	11.9	12.1	24.0
1978	12.6	13.8	25.4
1979	13.6	15.4	29.0
1980	15.1	16.6	31.7
1981	17.8	17.2	35.0
1982	22.1	[2] 14.3	36.4
1983 (estimate)	24.9	[2] 14.0	38.9
1984 (estimate)	31.8	[2] 14.0	45.8

[1] Includes military-related R&D programs of the Departments of Defense and Energy.
[2] Excludes NASA funding for shuttle production and operation, tracking and data acquisition activities, and related institutional support.

CHAPTER FOUR

Nondefense Programs

HENRY J. AARON *and associates*

Better the occasional faults of a government that lives in a spirit of charity than the consistent omissions of a government frozen in the ice of its own indifference.

—Franklin Delano Roosevelt

In this present crisis, government is not the solution to our problem; government is the problem.

—Ronald Reagan

THE 1983 budget continues the efforts of President Reagan and his administration to minimize the role of the federal government in all areas other than defense. In particular, the federal government is either being withdrawn from the provision of social services and income maintenance or having its activities curtailed.

President Reagan is forthright in stating the reasons for retrenchment. Services and protections offered by the federal government, in his view, are too numerous and too costly. State and local governments, the president holds, should decide whether or not to provide these services, how much to spend on them, and how to organize their delivery, without federal restrictions or financial support. The twin goals of higher spending for defense and lower tax rates, which the administration takes as immutable, lead inexorably to either intolerable budget deficits or drastically curtailed nondefense expenditures. Furthermore, the furor created by his proposals of May 12, 1981, to cut the long-run cost of retirement, survivors, and disability insurance benefits by 22 percent, has led the president to avoid any mention of reductions

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in social security in his 1983 budget. Instead, he has established a commission to make recommendations for amending the social security system, but not until after the November elections.

The 1983 budget proposes to cut nondefense spending on programs other than payment of interest to $43 billion below the current services level, lowering total spending in 1983 to $435 billion from the $478 billion that would be necessary to maintain programs at their current services level. These cuts come on top of the $27.1 billion in reductions enacted last year. Both these proposals would reduce the fraction of gross national product devoted to programs other than defense and interest from 15 percent of GNP in 1981 to 12.7 percent in 1983 and to 11.5 percent in 1985. Moreover, the cuts are unevenly divided; the major entitlement programs decline negligibly as a fraction of GNP over this period, while all other nondefense spending plummets (see table 4-1).

The reductions made in 1981 and those proposed this year constitute the Reagan administration's effort to eliminate or to reduce in size most of the social programs enacted during the last fifty years. Social security, medicare and medicaid, higher education assistance, aid to school districts on behalf of disadvantaged

Table 4-1. Nondefense Outlays in Constant 1981 Dollars, Fiscal Years 1981, 1983, and 1985

Billions of dollars unless otherwise specified

Outlay	1981	Projected 1983[a]	Projected 1985[a]	Percent of GNP 1981	Percent of GNP 1983	Percent of GNP 1985
Total nondefense	**497.4**	**466.4**	**451.6**	**17.4**	**15.6**	**13.8**
Interest	82.5	97.8	93.8	2.9	3.3	2.9
Nondefense less interest	414.9	368.6	357.8	14.5	12.3	11.0
Payments to individuals[b]	316.6	318.0	321.1	11.1	10.7	9.8
Social security and railroad retirement, medical care, and federal employee retirement and insurance	226.5	241.5	255.4	7.9	8.1	7.8
Other	90.1	76.5	65.7	3.2	2.6	2.0
Other nondefense	98.3	50.6	36.7	3.4	1.7	1.1

Source: Office of Management and Budget, "Payments for Individuals, 1983 Budget," February 1982 edition.

a. Deflated by the implicit index for all government spending derived from *Budget of the United States Government, Fiscal Year 1983*, p. 9-61.

b. Excludes payments to individuals included in the defense budget.

children, unemployment insurance, housing assistance, grants for urban and rural development, grants for training and job creation, financial aid to the poor, disabled, and elderly, grants for social services, and legal services for the indigent have all been the target of spending cuts proposed by the Reagan administration last year or this year.

In this chapter we examine some of these cuts in federal spending in the areas of income security, housing, health, and education and training. Because President Reagan's proposals express a coherent view of the appropriate role of the federal government in each area, we also review the rationale for creating the programs. The chapter builds on the tension between the view that these programs fulfill necessary responsibilities of the federal government and the contrary view that they are imposing heavy and unnecessary burdens on the economy.

What Is at Stake

Beginning with the New Deal of Franklin Delano Roosevelt and continuing through successive administrations, both Democratic and Republican, presidents and Congresses have established a series of programs to protect people from economic adversity, to guarantee them minimum quantities of basic goods, and to increase equality of opportunity. To achieve these goals, they created new federal agencies, modified the tax code to promote favored activities, provided grants to state and local governments and private organizations, and issued regulations mandating or prohibiting behavior of various kinds by governments, businesses, and individuals.

In the pursuit of these objectives, the federal government has become an increasingly visible, intrusive, and costly element in the economic and social life of the United States (see table 4-2). Spending has grown; income and payroll taxes have risen (though corporation income tax rates have declined). Federal employment has increased, but less rapidly than the civilian work force. A complex web of economic and regulatory relationships has formed, linking the federal government with subsidiary governments and with private businesses and organizations.

For most of the half-century during which the federal role was

Table 4-2. Selected Indicators of the Size of the Federal Government
Percent of GNP unless otherwise specified

Item	*1950*	*1960*	*1970*	*1981*	*1983 (projected)*
Taxes					
Personal income and payroll	7.6	11.1	14.1	16.4	18.4
Corporation income	4.0	4.3	3.4	2.5	2.7
Other	3.4	3.1	2.6	2.1	2.1
Federal employment					
Number (millions)	2.1	2.4	3.0	2.8	2.8
As percent of civilian labor force	3.4	3.4	3.6	2.6	n.a.

Sources: Office of Management and Budget, "Federal Government Finances," January 1980 edition, p. 9. Federal employment is from Bureau of the Census, *Statistical Abstract of the United States, 1980* (GPO, 1980), p. 318. The 1983 budget quotes full-time equivalents, which were initiated only in 1981. Civilian labor force is from *Employment and Earnings*, vol. 29 (January 1982), p. 9.
n.a. Not available.

growing, the economy was expanding, first after the low point of the Great Depression, then during the boom of World War II, and finally during the great postwar expansion that, punctuated by brief recessions, lasted until the early 1970s. Beginning in the late 1960s, however, inflation became progressively more serious, and since 1974 the rate of growth of productivity has been negligible, about 1 percent a year. The administration maintains that reducing the size, cost, and influence of government is a necessary precondition for bringing down inflation and restoring economic growth. Others believe that the economic role of the federal government was an important factor in assuring three decades of growth and price stability unprecedented in modern U.S. history.

The division between those who support an active role for the federal government in dealing with domestic social problems and those who feel that government usually creates more problems than it solves rests on two important trade-offs.

The first trade-off is between equality and efficiency. Most nondefense expenditures, other than those for interest on the national debt, occur under programs that provide benefits either to people who experience certain income-threatening events, such as reaching retirement age, becoming disabled, or losing a job, or to people who are judged needy. These programs help the elderly or the disabled to retire. They relieve workers of some of the

economic consequences of unemployment. And they provide the poor with income or with minimum quantities of certain basic commodities. The fraction of the population with money income below the poverty threshold dropped from 22 percent in 1960 to 13 percent in 1980, although there has been little decline since 1968 and the number of poor rose by 3.2 million last year. If in-kind benefits, which have risen faster than money income, are included, as few as 6 percent of the population may be below the official poverty threshold.[1] Also, the taxes levied to pay for these programs are somewhat progressive.[2]

The rationale for such programs is the common observation that many people do not or cannot plan adequately for economic adversity and that the outcomes of the marketplace are sometimes unjust because, in the words of Arthur Okun, they "allow the big winners to feed their pets better than the losers can feed their children."[3] Moreover, there is the plain aversion of many people to indigence, not only for themselves, but also for others. These programs do not seek to equalize incomes so much as to prevent serious declines in income and utter destitution.

Such programs carry a price, however. The most obvious is the taxes imposed to pay for them, which reduce the incomes that taxpayers retain for their own consumption and saving. Taxes distort decisions about how much to work and to save and what to invest in. Furthermore, the programs themselves affect behavior. Retirement benefits may be viewed positively as enabling the elderly to retire, or negatively as discouraging some from working who are capable of doing so. Likewise, welfare payments may be viewed as preventing destitution and providing protection against adversity, or as subsidizing sloth and promoting improvidence. Subsidies for medical care increase the access of the poor, the disabled, and the aged to care they could not otherwise afford, but they reduce the sensitivity of beneficiaries to the cost of care

1. Sheldon Danziger, "The Distribution of Income: An Account of Past Trends and a Projection of the Impacts of the Administration's Economic Program," prepared for the Joint Economic Committee, February 10, 1982.

2. See Joseph A. Pechman and Benjamin A. Okner, *Who Bears The Tax Burden?* (Brookings Institution, 1974), for estimates of the distribution of federal tax burdens.

3. Arthur M. Okun, *Equality and Efficiency: The Big Tradeoff* (Brookings Institution, 1975), p. 1.

and increase the likelihood of waste.[4] Thus there is a pervasive trade-off between the goal of helping people judged to be needy and that of minimizing inefficiencies by maintaining incentives based on the threat of economic adversity.

A second trade-off exists between providing help to as many people who need it as possible and not providing help to those who don't—in other words, between errors of omission and errors of commission. The lower the income ceiling for food stamp benefits, housing assistance, or welfare benefits, the smaller will be the number of people assisted who in some sense do not deserve help, but the greater will be the chance that some deserving people will be denied it. Strict rules for disability benefits minimize the number of people capable of working who will be awarded benefits, but increase the number of people for whom work is painful or impossible who will be denied benefits. Reducing social security benefits to people who retire before they reach sixty-five will cause some people who can continue working with little inconvenience to do so, but will impoverish many who are unable to work or who cannot find work.

In all such cases the fact that defined rules and regulations are necessary to minimize administrative caprice and that the average official is endowed with average wisdom means mistakes will invariably be made. The task of designing social programs is to arrive at a consensus of need and to decide how many people deserving of help should be denied it in order to minimize error, fraud, and abuse.

Many social programs enacted over the past half-century have been criticized as inefficient by people who embrace their objectives and agree that the federal government should be actively involved in income support, health, housing, and education. For example, student loans have been criticized because they provide unneeded subsidies to wealthy families; housing subsidies have been criticized because they are needlessly costly; health subsidies have been criticized because they provide excessive pay-

4. It is worth noting that both private and public "third party" payment systems produce the same effects. Evidence that third party reimbursement increases the demand for health care and that the effect depends on the proportion of total cost of which patients are relieved is reported in Joseph Newhouse and others, "Some Interim Results from a Controlled Trial of Cost Sharing in Health Insurance," *New England Journal of Medicine* (December 17, 1981), pp. 1501–07.

ments to some providers and insufficient payments to others. The 1983 budget accepts these criticisms. But it uses them primarily to justify budget cuts, not to design better ways of achieving previously accepted goals.

The 1983 budget may be read as a brief for leaving many of the nondefense functions now performed by the federal government to state and local governments or to the private sector. Congressional action on the president's 1983 budget is best understood, therefore, as a referendum on the wisdom of retaining a major federal role in the financing and provision of social services and income support. Acceptance of most of the president's budget amounts to agreement that many services previously assured by federal administration, financing, or regulation should be provided by lower-level governments with highly disparate fiscal capacities,[5] by private groups, or not at all. Rejection of most of his proposed cuts may be interpreted as a collective recommitment of the federal role in assuring social services and income support. The issue whether programs should be redesigned to achieve their objectives more efficiently than existing programs do is not seriously addressed in the 1983 budget. Nor does the budget recognize the inability of states or localities to deal with concentrated problems of poverty, because of their fear that if benefits are higher than average, taxpayers will flee to lower-cost jurisdictions and the poor will move in.

Table 4-3 summarizes the proposed reductions in a representative list of programs that provide income support and social services and that promote urban development. In this table and throughout the text *real outlays* refer to outlays in 1981 dollars.[6] Some programs are eliminated or cut to a small fraction of their former size, notably public service employment, other training and employment programs, and legal services for the poor. Others are scaled back by 20 to 40 percent, but the basic structure of

5. The Advisory Commission on Intergovernmental Relations compiles an index of fiscal capacity showing the ease with which different states can raise a given amount of revenue. The average value of that index for the top five states is 159.2; for the bottom five states it is 76.4. ACIR, *Tax Capacity of the Fifty States: Methodology and Estimates*, report M-134 (Government Printing Office, 1982), pp. 20–21.

6. The deflators used were derived from *Budget of the United States Government, Fiscal Year 1983*, p. 9–61. When applicable, the deflator for payments for individuals was used; in all other cases (unless otherwise specified), the deflator for "all other" nondefense expenditures was used.

Table 4-3. Effect of Congressional Action in 1981 and Reductions Proposed in the 1983 Budget on Real Outlays in Fiscal Year 1983

Billions of 1981 dollars unless otherwise specified

Program	*Outlay without cuts in fiscal 1982 or 1983*[a]	*Proposed outlay*	*Proposed reduction*	
			Amount	*Percent*
Education and training				
Elementary, secondary, and vocational education (budget authority)	6.7	3.9	2.8	42
Higher education (budget authority)[b]	10.7	6.0	4.7	44
Public service employment	2.4	[c]	2.4	100
Other training and employment programs	6.8	2.4	4.4	65
Health				
Medicaid	18.2	15.6	2.6	14
Medicare	47.4	44.5	2.9	6
Other health programs	4.3	4.0	0.3	7
Income support, income tested				
Food stamps and other nutrition programs	17.7	12.0	5.7	32
Aid to families with dependent children	8.1	5.9	2.2	27
Energy assistance	1.8	1.1	0.7	39
Housing assistance (units authorized in thousands)	230.6	−36.0[d]	266.6	. . .
Supplemental security income	8.0	7.8	0.2	3
Income support, not income tested				
Retirement, survivors and disability insurance, railroad retirement, and black lung	159.0	153.5	5.5	3
Federal retirement and disability	18.9	18.4	0.5	3
Unemployment insurance	23.9	19.8	4.1	17
Other				
Social services	6.5	4.5	2.0	31
Community development block grant and urban development action grants	4.4	3.4	1.0	23
Legal services	0.3	[c]	0.3	97

Sources: *Budget of the United States Government, Fiscal Year 1983*, pp. 5-93, 5-107, 5-130, 5-143; estimates for entitlement programs for 1983 without cuts, from *Budget of the United States Government, Fiscal Year 1983, Special Analysis A: Current Services Estimates;* and OMB, unpublished data.

a. 1983 outlays or budget authority without cuts equal: for entitlement programs, current services estimates as presented in the 1983 budget plus the estimated reductions in 1983 outlays attributable to actions taken by Congress last year, reduced to 1981 dollars by deflators implicit in table 22 of the 1983 budget; for other programs, outlays equal actual 1981 outlays. Proposed outlays equal estimated 1983 outlays from the 1983 budget, deflated to 1981 dollars by the deflators implicit in table 22 of the 1983 budget.

b. Includes social security student benefits, which are also included under retirement, survivors and disability insurance, railroad retirement, and black lung.

c. Less than $50 million.

d. The net reduction in units represents the balance of 121,000 units authorized for assistance in 1983, less 157,000 cancelations of units authorized in previous years.

many of these programs is transformed, and further cuts are promised. In this second category are elementary, secondary, and vocational education, higher education assistance, food stamps and other nutrition programs, aid to families with dependent children, energy assistance, social services block grants, and community development and urban development block grants. Because many of these programs are scheduled to be turned over to states or to be consolidated into block grants, over the spending of which the federal government would exercise few controls, the budget says little about structural reforms to improve their efficiency.

A third category of programs, including medicare, medicaid, supplemental security income, social security cash benefits, and unemployment insurance, are all retained by the federal government but cut in size, either by actions taken in 1981 or by the 1983 budget. The reductions shown in table 4-3 represent the down payments on future reductions that will flow ineluctably from actions already taken, that are sought by the 1983 budget, or that the administration has clearly indicated it intends to seek.

Income Security

The federal government took up the task of supporting the incomes of needy and dependent people in 1935, when Congress passed the Social Security Act. That law set in place unemployment insurance, retirement and survivors insurance, and aid to families with dependent children (AFDC). Later Congresses initiated housing assistance, disability insurance, food subsidies, and energy assistance. With the notable exception of AFDC, real federal expenditures under each of these programs rose during the 1970s. Now they have all been cut or are the subject of cuts proposed in the 1983 budget. Moreover, the president's proposal that the states assume full responsibility for AFDC and food stamps in exchange for federal assumption of responsibility for medicaid would remove the federal government from involvement with income-tested cash assistance to the nonaged poor.[7]

Aid to Families with Dependent Children

AFDC provides cash assistance to low-income families—usually single-parent families—with dependent children present. The

7. See chapter 5 for an examination of this proposed swap.

states administer AFDC (99.5 percent of the people involved in its administration are state employees) and set benefit levels, but the federal government shares 50 to 77 percent of the total cost of the program. Because states have failed to raise AFDC grants in line with inflation, average benefits for a family of four have fallen 28 percent in real terms since 1972.

In his 1983 budget President Reagan proposes to reduce real federal outlays on AFDC and related programs from $8.5 billion in 1981 to $5.9 billion in 1983, a 31 percent reduction. Of this reduction, $1.3 billion was enacted last year. Proposed changes in the definition of family needs and available family income account for most of the 1983 savings. Family units in larger households will have their basic benefits reduced. Families receiving low-income energy assistance will have this assistance counted in determining available income, so that their AFDC grants will be reduced. The president proposes to require state "workfare" programs, under which recipients of cash assistance would have to work at specially created jobs in order to receive assistance. He is also asking Congress to provide new incentives for states and localities to enforce child support laws, thus reducing the dependence of children on public support. The savings from these proposals are estimated to be $1.3 billion in 1983.

The administration also wants to consolidate and cut federal grants for administering AFDC, food stamps, and medicaid. The 1983 budget proposes not only to reduce grants for administration, but also to reduce and eventually to eliminate any federal sharing in the cost of payments erroneously made. But no penalties will be imposed on states for denial of benefits to people who turn out to have been eligible. Thus the budget unmistakably conveys the message that the administration will not tolerate unjust benefit awards, but is not concerned about unjust denials.

The proposed administrative consolidation of AFDC and food stamps makes sense, but it would bring few substantive changes, because these two programs cover overlapping populations and are already administered by the same state and local agencies. The conversion of the federal grant for administrative expenses from a matching grant to a block grant will undoubtedly induce states to economize on administrative costs, probably to the disadvantage of beneficiaries.

Starting in 1984, the president proposes to turn over to the

states all responsibility for financing and administering AFDC and food stamps. The resulting change in the method of financing these programs would drastically alter the incentives facing state legislatures and governors. At present, states pay on average 46 percent of each additional dollar of AFDC benefits and none of the cost of food stamp benefits. Thus the federal support of the two programs offsets the widely stated fear that providing benefits for the needy at the state or local level will drive up local taxes and drive away business and the affluent. This fear would grow under the administration's plan to give states or localities full financial responsibility for all aid to the poor, and would probably lead to continued and accelerated reductions in that aid.

The changes in AFDC proposed for 1983 (before the program is handed over to the states) continue a pattern established with the president's proposals for 1982. The structure of the program remains unchanged, but proposed technical changes would disqualify some families—especially those with a prime-age potential worker—and reduce the benefits of many more. The reforms enacted last year hit families that have a wage earner especially hard. Until 1981, benefits were reduced by 67 cents for each dollar of earnings in excess of work-related expenses and a $30 a month disregard. As a result of legislation enacted last year, benefits after four months are reduced by a dollar for every dollar of earnings, a 100 percent tax. Also, allowable work-related expenses used in computing net income are sharply reduced. These and other changes add to the restrictiveness of federal welfare regulations, limiting local administrative control of the program and increasing the burden of management.

Supplemental Security Income

Supplemental security income (SSI) is a federally financed cash assistance program for the low-income elderly, disabled, and blind. Some states supplement federal benefits. If no changes are made in the program, 1983 federal outlays on SSI are expected to be $9.2 billion, up 15 percent from 1982. This rise is due both to the indexing of basic benefits and to the quirk that thirteen rather than twelve monthly SSI payments will be made in 1983.[8]

8. Because the first day of fiscal 1984 falls on a weekend, the SSI payment otherwise due on that day will be made in fiscal 1983.

As in the AFDC program, the president proposes technical changes in the payment formula and eligibility definitions that would reduce 1983 expenditures by $300 million, or about 3 percent. Many of these changes are minor and will lower the annual payments to beneficiaries by only a few dollars. But the president also proposes to tighten the definition of disability and disqualify about 115,000 people now receiving SSI disability benefits. With this exception, however, the SSI program has escaped the large reductions proposed for other assistance programs.

Food Stamps and Other Nutrition Assistance

Federal spending on food and nutrition assistance rose irregularly, but rapidly, during the 1970s. Real outlays in 1981 were $16.2 billion, or about 88 percent, higher than in 1973. But the rise in per capita real food stamp benefits from 1974 to 1981 was not large enough to offset the decline in real benefits for AFDC families. A family receiving only AFDC and food stamps qualified for about 18 percent less in combined real benefits in 1981 than in 1974. In fact, combined AFDC and food stamp benefits in 1981 for a family of four with no earnings were 4 percent lower in real terms than AFDC benefits alone in 1969, when the food stamp program was not yet nationally available.

In his 1983 budget President Reagan proposes to continue the reduction of food stamp benefits initiated last year. Real spending is projected to decline by 20 percent from its 1981 level. None of the food stamp proposals for 1983 will alter the fundamental nature of the program. All changes are technical and will principally affect families that receive low-income energy assistance or that have a potential wage earner. The president proposes that energy assistance be counted as income in determining food stamp benefits, that earnings disregards be eliminated (effectively raising the tax on earnings), and that the rate at which benefits are reduced as all forms of net family income (including earnings) increase be raised from 30 to 35 percent. The cumulative effect of the latter two changes would be to raise the tax rate on gross earnings in the food stamp program from about 25 to 35 percent and lower the proportion of increased earnings that food stamp recipients will retain. Other reductions would result from eliminating monthly

payments of less than $10 and modifying the benefit-rounding convention to the disadvantage of beneficiaries.[9]

Federal outlays for administrative expenses would be reduced by providing a block grant rather than a matching grant for state and local expenses; and federal reimbursements for benefit overpayments would be phased out over the four years ending in 1986. Both these changes would increase incentives for states and localities to adopt rules that minimize payments to ineligible families, even at the expense of denying payments to those that are eligible. The administration also proposes beginning in 1984 to turn over to state governments all financial responsibility for food stamps.

In addition, the 1983 budget proposes to abolish the special milk and summer feeding programs. The school breakfast, child care feeding, and women, infants, and children programs would be converted from entitlement programs to block grants with reduced budgets. The president expects these changes to save $300 million in 1983. Real federal outlays on nutrition programs other than food stamps would be down 30 percent from 1981.

The proposed changes in federal nutrition assistance programs will affect all classes of beneficiaries—children, prime-age workers and other adults, and the very old. Such changes as eliminating the special milk program and increasing the food stamp tax on earnings will primarily affect families with modest incomes that are at the upper end of the eligible range, and will probably not have serious nutritional consequences. But such changes as turning the nutrition program for pregnant women, new mothers, infants, and children into a block grant and counting energy assistance in the computation of food stamp benefits are likely to reduce significantly the well-being of the most disadvantaged, especially the very young and the very old. Although there is a sound argument for concentrating nutritional assistance on the most disadvantaged, the president's proposals go beyond this objective and reduce assistance to all types of beneficiaries, even those with no resources of their own. Even the "less disadvantaged," whose nutritional assistance will be reduced by these proposals, are far from well-to-do; nine-tenths of the proposed

9. Monthly benefits will be rounded to the next lowest dollar, thus reducing payments by a few dollars a year.

nutritional cuts are focused on food stamps, a program restricted to families with incomes below 130 percent of the poverty line.

Emergency and Energy Assistance

Since 1979 the federal government has provided block grants to states to help low-income families pay for sharply increased fuel bills. This program protects many of the poorest families from some of the loss they suffered when fuel prices rose after the decontrol of energy prices. The promise of such aid diminished political opposition to the decontrol of energy prices and helped secure passage of legislation that improved the efficiency of the allocation of energy. The Reagan administration now proposes to modify and greatly reduce the low-income energy assistance program. The 1983 budget would combine the grant for energy assistance with the grant for emergency assistance, permit states to apply the combined block grant for hardship assistance as they wish, and reduce outlays to $1.3 billion, 30 percent below expenditures in the last two years. A separate requirement would require states to count energy assistance in determining food stamp and AFDC benefits. This requirement would cause AFDC payments to be cut by up to one dollar and food stamps by 35 cents for each dollar of emergency assistance. As a result, the effective reduction in energy assistance for the poor is far larger than the 30 percent cut in the energy assistance budget. As price controls on gas are phased out and natural gas prices rise, real assistance levels will plummet.

The proposal to take energy assistance into account in the computation of food stamps is inconsistent with the original purposes of both programs. Food stamps help low-income families attain minimum nutritional standards; energy assistance reduces financial hardships arising from the recent rises in energy costs. Under the president's proposal, food stamp aid will decline even though there is no real change in the resources families need to purchase a nutritionally adequate diet.

The Cumulative Effect of Welfare Cuts

The 1983 budget proposals extend President Reagan's cuts in aid to the needy. In 1981 the federal government spent on the needy $33.7 billion through the two cash assistance programs—

AFDC and SSI—and two categories of in-kind assistance programs—food stamps and other nutrition assistance, and low-income energy assistance. If all the president's 1983 proposals were enacted, real spending in 1983 would fall to $26.8 billion, with reductions concentrated in AFDC, nutrition programs, and energy assistance.

Outlays on these programs would decline from just over 1.18 percent of GNP in 1981 to 0.78 percent in 1983. Although the proposed swap of medicaid for food stamps and AFDC, examined in chapter 5, makes projections uncertain, the budget projects a further decline to 0.58 percent of GNP in 1985 if President Reagan's proposals are adopted.[10] Although expected improvements in economic conditions account for part of the reduction, it is the cumulative impact of many small changes in payment formulas, all tending to reduce real benefits to low-income families, that accounts for most of the drop. Because there are so many changes, it is hard to identify the groups that lose most. The increased taxes on income—especially wage income—suggests that low-income families with an earner or potential earner would be hardest hit by the proposed changes.

If beneficiaries get less for working than they did in the past, they would seem to have less incentive to work.[11] But the efficiency argument against raising marginal tax rates is weak. Recent evidence supports the commonsense view that a rise in the rate at which benefits are reduced as earnings rise will discourage work by people who continue to receive benefits.[12] But increasing the rate of benefit reduction lowers the number of people who receive benefits and who are exposed to the program's work disincentives. The net effect is likely to be small.

The fundamental issue is fairness. The largest proposed cuts hit programs for the nonelderly, like AFDC and child nutrition, or programs like food stamps and energy assistance that serve all

10. By comparison, expenditures on these programs equalled 1.10 percent of GNP under the last budget prepared by President Ford.

11. Tom Joe, "Profiles of Families in Poverty: Effects of the FY 1983 Budget Proposals on the Poor," working paper (Washington, D.C., Center for the Study of Social Policy, 1982).

12. Robert A. Moffitt, "An Economic Model of Welfare Stigma," working paper, October 1981, p. 27; and Frank S. Levy, "The Labor Supply of Female Heads, or AFDC Work Incentives Don't Work Too Well," *Journal of Human Resources*, vol. 14 (Winter 1979), pp. 76–97.

age groups. Programs principally for the elderly and disabled, like SSI and medicare, receive much smaller reductions. Families with an earner present suffer the sharpest reductions. The injustice that arises when families with a full-time earner have no more income, and possibly even less, than families dependent exclusively on assistance will be exacerbated. The Reagan changes compress the income distribution among the nation's disadvantaged families by narrowing the income gap between low-income families with wage earnings and those without. Simultaneously, they widen the gap between families with low earnings and those with high earnings, because they deprive the former of income supplements to their wages. Whether the resulting changes in the welfare of different groups are regarded as good or bad will obviously depend on a social judgment.

Social Security

In some ways the most remarkable aspect of the 1983 budget is its failure to propose any changes in retirement, survivors, and disability insurance under the social security system. This program accounts for one-third of nondefense expenditures other than interest, provides benefits to 36 million people, and has grown continuously and rapidly. Despite the size of the program and a looming deficit, the 1983 budget is silent on changes in social security.

The reason for such forbearance is clearly political. On May 12, 1981, the administration proposed a long list of cuts in social security benefits that would have reduced expenditures in fiscal 1982 by $2.5 billion and that would have reduced the long-run cost of the system by more than 22 percent. This proposal generated opposition remarkable for its unanimity. The Senate voted 96 to 0 to disassociate itself from one of the major elements of the proposal, the sharp cutback in early retirement benefits effective in less than seven months.[13] The administration rapidly conceded that it would consider other cuts that would save as much as the ones it had put forward, but the proposal continued to provoke intense and angry criticism. On September 24, 1981, the president

13. Harrison Donnelly, "Senate Opposes Social Security Cuts," *Congressional Quarterly* (May 23, 1981), p. 895.

announced in a televised address that he would not press for action on his proposals, but instead would create a commission to study the social security system and its problems and to make recommendations for changes. The commission was instructed to submit its report by December 31, 1982, after the midterm elections.

Dealing with the social security system presents the administration with severe political problems that arise from the structure of the system, the peculiar financial difficulties that it is experiencing, and the powerful political support it enjoys with most voters. Payroll taxes levied on employees and employers flow into three trust funds, from which retirement and survivors benefits, disability benefits, and medicare hospital insurance benefits are paid. The balance of the retirement and survivors insurance trust fund is declining and will soon reach zero if no action is taken, but the two other trust funds have surpluses for the time being. Last year Congress authorized the trustees to shift resources among the three funds through "interfund borrowing." At that time it appeared that this flexibility alone would cover benefit payments until 1985, when a scheduled increase in payroll tax rates would generate increased revenues. The worsening recession has made clear, however, that even if reserves of all three funds are pooled and combined with total payroll tax collections at legislated rates, revenues may not be sufficient to meet all benefits promised under current law beyond 1984.[14] Thus, not later than 1983, Congress will have to take steps either to increase revenues (by raising payroll taxes, permitting the trust funds to borrow from the Treasury, or allocating other taxes to social security) or to cut benefits.

After this problem is dealt with, the cost of cash social security benefits as a percent of taxable wages will not rise for about three decades. In the first decade of the twenty-first century the cost of social security will begin a three-decade-long rise, as children born during World War II and the postwar baby boom retire. The cost of social security as a percent of taxable wages will rise by about 40 percent. Tax increases already legislated will cover some

14. *Summary of the 1982 Annual Reports of the Social Security Boards of Trustees*, p. 10.

of that rise and will be sufficient to cover benefits for the next fifty years, but more revenues will be necessary to meet legislated benefits after about 2030, according to current estimates.[15]

This long-run problem is almost entirely independent of the short-run financing difficulties with which Congress must soon deal. The large deficits in the Reagan budget, despite the draconian cuts in nondefense spending other than social security, have led members of Congress to suggest alternative budget strategies that entail significant immediate cuts in social security.[16]

Congress faces two decisions with respect to social security: whether to take up the issue as part of its deliberations on the 1983 budget or to wait until next year, and whether to address only the immediate financial difficulties or to take on the long-term deficit, as well. In making this decision, members of Congress must take into account the administration's desire, shown by last year's proposals, to make drastic reductions in social security benefits. A decision to make some short-run cuts, such as deferral of part or all of the cost-of-living increase, would solve the short-run financing problems of the system and let Congress duck the long-run question for the time being. A decision to wait until next year to take up the issue, after the commission created by President Reagan makes its recommendations, would heighten pressure on Congress to deal with the long-run financing questions as well.

Housing and Urban Policy

The Reagan administration has assigned most federal urban-related programs low priority and considers them useful offsets for real increases in such other budget categories as defense. The administration is rapidly withdrawing from previous commitments to spend federal money in urban areas (see table 4-4).

The main issue for federal policy toward urban areas is how the federal government can help big cities cope effectively with the

15. The Social Security Act requires the annual presentation of estimates of costs and revenues of the retirement, survivors, and disability insurance systems over the succeeding seventy-five years. Traditionally the actuaries have presented three estimates. In 1981 they presented five. The statements in the text refer to projection IIB, which is based on intermediate assumptions about economic and demographic events.

16. Senator Ernest F. Hollings (Democrat of South Carolina) and Senator Pete V. Domenici (Republican of New Mexico) have each put forward plans under which the annual cost-of-living adjustment in social security would be skipped for one year.

Table 4-4. Outlays for Urban and Regional Programs in Constant 1981 Dollars, Fiscal Years 1981, 1983, and 1985

Billions of dollars unless otherwise specified

Program	1981	Projected 1983	Projected 1985
Community development block grant	4.0	2.9	2.7
Urban development action grant	0.4	0.5	0.4
Economic Development Administration and Appalachian Regional Commission	1.0	0.5	0.1
Other community and regional development	2.4	2.3	2.0
Total	7.8	6.2	5.2
Addendum			
Housing assistance (net number of units newly authorized for assistance)	230.6	−36.0	n.a.

Sources: *Budget of the United States Government, Fiscal Year 1983*, p. 5-93; and Department of Housing and Urban Development, *Summary of the HUD Budget for Fiscal Year 1983* (HUD, 1982), p. H-5.
n.a. Not available.

fiscal consequences of heavy concentrations of poor people. Providing such help has long been regarded as a proper federal role because poverty results in part from the operation of the national economy and because big cities contain a disproportionate share of the poor.

Past experience indicates that poverty, unemployment, crime, arson, drug addiction, and related maladies among the unskilled urban poor remain disproportionately high even during periods of high economic growth and low unemployment at the national level. In 1980 the fraction of people in central cities with incomes below the official poverty level was 17.2 percent, higher than the 15.4 percent in nonmetropolitan areas, and more than double the 8.2 percent in all suburbs combined.[17] Moreover, aiding the poor requires some federal involvement. State or local governments cannot effectively alleviate the problems of the poor, because they fear that if they try to tax the nonpoor heavily to aid the poor, many of the nonpoor will move, usually to nearby suburbs where taxes are lower and they command a political majority. Hence only the federal government, with its relatively inescapable tax system, can finance assistance to poorer citizens and the local governments that serve them.

17. Bureau of the Census, *Current Population Reports*, series P-60, no. 127, "Money Income and Poverty Status of Families and Persons in the United States: 1980" (Advance Data) (GPO, 1981), p. 4.

Recognizing these facts, every administration in recent decades has supported programs that extend financial aid to certain areas. The Nixon administration, for example, initiated community development block grants. The Carter administration spent billions of dollars in its first two years on various antirecession programs tilted toward big cities, assisting both their residents and their governments. Examples are local public works grants, comprehensive employment and training programs, and countercyclical revenue sharing. This aid declined in the last two Carter years but remained sizable through fiscal 1981. Big-city governments received over 40 percent of their revenues from transfers directly from the federal government or from states (which in turn received aid from the federal government).

Most of these programs have been condemned as failures by the Reagan administration, with varying degrees of accuracy. But even programs that produced little useful real output transferred income to hundreds of thousands of low-skilled, low-income urban citizens who were having difficulty finding employment in the private economy. Insofar as the Reagan budget recognizes the problems caused by concentrated urban poverty, it proposes mainly to rely on private-sector economic growth and locally raised public-sector revenues.

Community and Regional Development

The budget explicitly identifies community and regional development as areas where federal spending should be reduced, both to ease budgetary strains and to "get out of the way" of the private sector. The budget authority for both the Economic Development Administration and the Appalachian Regional Commission is virtually eliminated in 1983, a saving of $817 million from 1981. Real outlays taper off more gradually, from $961 million in 1981 to $492 million in 1983 and $132 million in 1985. (Other regional economic development commissions were abolished earlier.) These agencies are good candidates for elimination. The actions of both have always been gestures of federal concern, more symbolic than effective in reviving the depressed areas they were supposed to serve.

Real spending on community development block grants and urban development action grants is scheduled to fall by 23 percent

from 1981 to 1983, and by 30 percent from 1981 to 1985. Obligational authority in nominal terms is constant at $3.9 billion a year from 1982 through 1985, after a drop from $4.4 billion in 1981. These grants are an important way of providing public support to city governments and of helping them cope with their disproportionate share of the nation's poor residents. The money can be used for many physical improvements at the discretion of local governments. The budget states that by not giving inflation allowances for discretionary programs, the federal government "will provide a powerful incentive to reduce overhead, waste, and low-priority activities."[18] It seems likely that a 30 percent real cut in four years will reduce "truly productive" activities too.

Although the 1983 budget frowns on urban areas, it smiles on the countryside. Real spending on rural development in 1983 is 27 percent higher than in 1981, though it falls back close to the 1981 level by 1985. As a result, federal spending on rural development rises from 19 percent of combined community development block grant and urban development action grant outlays in 1981 to 31 percent in 1983 and 28 percent in 1985. The budget provides no explanation for this disparity of treatment. Many rural areas have grown rapidly in population and need added community facilities, but the problems faced by urban areas continue to be serious.

Altogether, outlays on community and regional development are scheduled to fall in real terms from $9.4 billion in 1981 to $6.3 billion in 1983 and $5.3 billion in 1985—declines of 33 percent and 44 percent, respectively, from 1981. About $1 billion of this drop results from assuming that no further disasters like the Mount Saint Helens eruption will occur, but the rest consists of genuine cutbacks.

Housing Subsidies

Because expenditures for housing assistance start several years after initial commitments, housing subsidies will continue to increase from 1981 through 1985 despite sharp cuts in the number of units to be added. Outlays on housing assistance in real terms rise from $6.9 billion in 1981 to $7.8 billion in 1983 and 1985 (up 13 percent over 1981). In contrast, nominal budget authority for

18. *Budget of the United States Government, Fiscal Year 1983*, p. M18.

housing assistance plummets from $26.1 billion in 1981 to −$3.9 billion in 1983 and $2.1 billion in 1985.[19]

This drop reflects a major policy decision to end almost all subsidies for newly constructed units and to slash commitments to other housing assistance as well. The Department of Housing and Urban Development (HUD) plans to cancel about half the 700,000 new subsidized units in process or under construction in 1982. After 1983 HUD will authorize construction of only 10,000 new subsidized units a year (exclusively for the handicapped and the elderly), more than 90 percent fewer than the 111,600 new or substantially rehabilitated units authorized in 1981 and than comparable totals in preceding years. Nevertheless, HUD expects the number of subsidized units to rise from about 3.4 million at the end of 1981 to about 3.8 million at the end of 1985. Half this increase of 100,000 units a year will come from completion of units already in progress, the other half from assistance under a revised housing voucher program. Under this program eligible households would be given a certificate whose value would depend on local housing costs and family income. Households could use the voucher to pay for all or part of the cost of any rental housing unit they might select.

The voucher program resembles the section 8 existing rental housing program, under which eligible households receive subsidies based on family income, but only if they reside in specified existing housing units.[20] The voucher program contains three administrative changes designed to improve cost-effectiveness. Payments under the voucher program will depend solely on incomes of assisted households and average area-wide housing costs, not on individual rents. Each household will be free to negotiate its own housing arrangements with no rent ceiling, as long as it occupies a standard unit. And assistance will be provided in five-year, no-increase contracts with households, rather than fifteen-to-forty-year contracts with landlords. Present section 8 existing rental housing contracts will gradually be converted to

19. For housing programs, budget authority is the sum of new budget authority in the current year less rescissions of previous budget authority. The 1983 budget would rescind $3.9 billion more of budget authority from years before 1983 than it would provide in 1983.

20. Section 8 consists of two parts. Under one part, subsidy contracts are tied to the construction of new housing units. Under the other, subsidies are provided to tenants of existing housing units.

this same arrangement. Experience with the Experimental Housing Allowance Program, a multiyear study of housing vouchers, indicates that these improvements will induce recipients to strike improved bargains with their landlords.

About 111,600 households will be authorized to receive aid through such vouchers in 1983. About 60,600 of these households will be shifted from present rent subsidy programs; 30,000 will be housed in units to be rehabilitated under a new program that is to provide grants of up to $5,000 a unit; and 10,000 will be placed in units now owned by HUD.

Assistance to occupants of existing public housing units will also be cut. The fraction of income required for rent will rise from 25 to 30 percent, and the cash value of food stamps will be included in the income used as a base for computing rents. Families in public housing that receive food stamps will experience a rent increase in 1983 averaging 26 percent, though their rents will still be significantly below those available in the private sector.

HUD defends these cuts in federal housing aid on three grounds. First, the administration holds that its economic program will boost the incomes of the poor and reduce their need for housing subsidies. Second, budget cuts, it is argued, must be made somewhere, and housing subsidies are a reasonable target, because the vast majority of Americans—including most poor households—are well housed. Third, creation of new subsidized housing can be ended because the existing inventory, plus new unsubsidized private construction, is sufficient to provide basic shelter for everyone. As HUD points out, "the major housing challenges we now face are how to help the very poor afford decent housing, how to maintain and preserve the existing housing stock, and how to assure equal opportunity and access to housing markets for all households."[21] Thus the key housing problem of the poor is no longer physically inadequate units, but high housing cost. In 1979 the fraction of renters paying 50 percent or more of their incomes for rent was 49 percent among those with incomes under $7,000, and 73 percent among those with incomes under $3,000.[22]

21. Department of Housing and Urban Development, *Summary of the HUD Budget for Fiscal Year 1983* (HUD, 1982), p. H-2.

22. Bureau of the Census, *Current Housing Reports*, series H-150-79, *Annual Housing Survey, 1979*, pt. C: "Financial Characteristics of the Housing Inventory" (GPO, 1981), p. 7.

Does it make sense to curtail financial assistance when high housing expense, rather than physically inadequate housing, is the main housing problem faced by the poor? It is certainly sensible to shift from subsidizing costly new units for the poor to helping them pay rents on existing units. But it does not seem reasonable to cut back on the second kind of assistance too—unless other income assistance to the poor is simultaneously being expanded. But in fact it is being cut.

Furthermore, the administration's increased reliance on the existing housing inventory and unsubsidized new construction to aid the poor coincides with two factors likely to create at least a mild rental housing shortage. First, high interest rates in 1981 and 1982 have depressed new housing construction. Second, housing demand will increase as more people born during the baby boom reach their late twenties and early thirties. Also, because the real cost of homeownership is much higher in the 1980s than in the 1970s, housing demand is likely to shift from owner-occupied housing to rental units. As a result, rents will probably rise faster than consumer prices generally for the first time in twenty years.

For many years the designers of urban policy have been unable to resolve the conflict between providing aid for people, such as income support or social services, and providing aid to places, such as grants for commercial redevelopment or new housing. The Reagan administration has resolved that conflict by seeking major reductions in both.

Urban Transportation

Real federal outlays on ground transportation will fall from $17.1 billion in 1981 to $11.4 billion in 1983 (down 33 percent) and to $9.7 billion in 1985 (down 43 percent from 1981). Specific declines from 1981 to 1983 stated in 1981 dollars are $2.6 billion in railroad subsidies (down 71 percent), $1.8 billion in highway subsidies (down 20 percent), and $1.1 billion in urban mass transit subsidies (down 28 percent). The most important of these reductions for cities is in urban mass transit aid, because federal operating-cost subsidies will be eliminated. In 1981 the federal government paid about 15 percent of the operating costs of all urban public transit systems. The administration proposes to continue some capital subsidies, though not for new fixed-rail systems, which are more costly to build and operate than alter-

native modes of transportation. But it also plans to phase out operating-cost grants over a three-year period. It argues that federal subsidies have let local governments avoid raising fares to cover costs and have perpetuated inefficient forms of service.

Not only are these claims valid, but federal subsidies also contribute to another major inefficiency: high wage settlements by labor unions with power over wage levels and organization of local transit service. Transit drivers are paid as much as $12 an hour, as against $5 an hour for taxi drivers and nothing for the millions of auto commuters who drive themselves. In 1978 over half of all federal spending on urban highways and mass transit went into mass transit, which accounted for only 3 percent of all urban passenger miles traveled.[23]

Withdrawal of federal subsidies for operating costs would create critical problems for many public transit systems. Systems that provide overexpensive service to low-density areas at fares below cost will change to less extensive routes and more diversified services, not confined to those operated by union-wage drivers. Such services could include jitneys, taxis for the elderly and handicapped paid for by vouchers, van pools partly financed by employers, and higher-priced peak-hour buses.[24]

Because mass transit is locally produced and consumed, placing responsibility for both funding and operating it on states and localities appears sensible. Abolition of federal subsidies would force localities to confront the true costs of their present transit services, which are now masked by those subsidies. The transition would be painful in many cases, especially for the New York area, which has 32 percent of all mass transit patronage. But it should improve the efficiency of the transportation system.

Complete abandonment of responsibility for mass transit operations by the federal government raises two important equity issues. One concerns the disparity of resources among different regions. It seems reasonable for each region to pay for its own public services, like mass transit, but such energy-rich states as Oklahoma have abundant taxable resources, while others like

23. This estimate applies to spending in 1975. It was made by Alan Altshuler in *The Urban Transportation System: Politics and Policy Innovation* (MIT Press, 1979), p. 35.

24. For an excellent analysis of the future of urban mass transit, see Milton Pikarsky and Christine M. Johnson, "After the Dust Settles: Transit in Transition," working paper (Chicago, 1981). Pikarsky is at the Illinois Institute of Technology Research Institute, and Johnson is with the Checker Taxicab Company.

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Maine do not. Is it just that the former with lower tax rates can buy much better public services, in general, and mass transit services, in particular, than the latter can?

The second issue arises because mass transit is used disproportionately by people with little income, the aged, and those with disabling handicaps. In the United States public transit is mainly an "inferior good"; that is, as soon as you can afford a car, you stop using the bus. Thus many transit patrons—especially those who travel outside of rush hours—cannot afford private cars, or cannot use them because of handicaps. Forcing transit systems to raise prices would increase the economic burden on these involuntary patrons, many of whom are poor. However, the most deprived could often be provided superior service by alternative systems that do not cover such extensive routes or use such expensive drivers. Examples are taxi service for the handicapped or non-union-driven van service for the elderly. In the case of public mass transit, therefore, the stimulus to greater efficiency caused by withdrawal of federal operating-cost subsidies probably outweighs the negative effects.

Health

Federal health policy has long pursued three objectives that now are in open conflict with one another. The federal government has tried to improve access to medical services of the poor, the aged, and selected groups such as Indians. It has underwritten the largest program of biomedical research in the world, principally through the National Institutes of Health. Finally, it has sought to hold down the costs both of its own programs and of those financed by private expenditures or by state or local governments.

The 1983 budget sustains federal interest in research and emphasizes cost containment, but signals a broad retreat in efforts to improve the access to medical care of groups that cannot afford it.

The Health Budget

Expenditures on health care are among the most rapidly growing in the federal budget because of rising outlays under medicare (see table 4-5). Medicare has covered the aged since it began in

Table 4-5. Outlays for Federal Health Programs in Constant 1981 Dollars, Fiscal Years 1981, 1983, and 1985

Billions of dollars

Program	1981	Projected 1983	Projected 1985
Medicare	39.1	44.5	50.2
Medicaid			
Federal	16.9	14.9	16.3
State	13.2	14.4	n.a.
National Institutes of Health	3.4	3.1	2.8
Other[a]	6.6	5.8	5.2

Sources: *Budget of the United States Government, Fiscal Year 1983*, p. 5-130; and Health Care Financing Administration, unpublished data.

n.a. Not available.

a. Excludes Department of Defense and Veterans Administration programs, Federal Employees Health Benefits, health-related student loans, and assistance to health maintenance organizations.

1966 and the disabled and those with end-stage kidney disease since 1973. Medicaid, the next largest federal health program, pays for acute and long-term care for recipients of AFDC, for the aged and disabled poor, and, in thirty states, for the "medically indigent," or people with low incomes who are not receiving welfare. To obtain federal matching grants under medicaid, states must offer seven mandatory medical services and cover all persons who are receiving supplemental security income or aid to families with dependent children. But states may cover additional people and offer additional services. The rest of the health budget will have been reduced 11 percent in real terms between 1981 and 1983 if all changes proposed by the president are adopted. These outlays consist of $4 billion on health research, mostly by the National Institutes of Health, $1.5 billion on four new block grants created last year that absorbed many grant programs, and the remainder on a variety of programs that for the most part were significantly cut last year and are slated to be cut again this year.[25]

Under medicare and medicaid the federal government, with some help from the states, has shouldered primary responsibility for financing medical care for groups that have great need for care but often little capacity to pay for it. Both programs have tried to

25. The budget does not include in the health function the large expenditures for health care undertaken by the Defense Department for members of the armed services and their families and by the Veterans Administration or health insurance premiums for federal employees.

bring their beneficiaries into the mainstream of American medical care, paying for almost the same care, in the same institutions, that is available to more affluent Americans.

The results have been impressive. All indicators show that the elderly use hospital and nursing home services far more than they did before medicare. The poor that are covered by medicaid now use about as much medical care as the more affluent. The increased use of medical services may have contributed to the large gains in life expectancy among the elderly since 1965 and to the sharp drop in infant mortality, especially among blacks.[26]

National medical expenditures have also risen dramatically in constant 1980 dollars, from $124 billion, or 6.0 percent of GNP, in 1965, to $247 billion, or 9.4 percent of GNP, in 1980. The main forces behind this growth have been the increased range and power of medical services and the rising income of American consumers, accompanied by spreading third-party coverage, since World War II. The aging of the population has contributed only slightly to past increases in health care expenditures, but it will be more important in the future.

Background on Efforts to Contain Costs

By the early 1970s it was clear that the growth of medical expenditures, both governmental and national, was not a temporary problem, but one with deep and persistent causes. The first efforts to slow the growth of federal expenditures did not alter the basic nature of medicare and medicaid. In 1972 Congress authorized professional standards review organizations, groups of physicians charged with reviewing hospital stays for medicare and medicaid patients and empowered to disallow payment for medically unnecessary services. The same legislation gave medicare administrators the right to limit hospital payments. Individual states began to require hospitals to obtain state approval before undertaking major investments, seeking thereby to eliminate "unnecessary" or duplicative facilities. In 1974 Congress required all states to enact legislation requiring health care providers to obtain a certificate of need for new investments and stated that payments under the Public Health Service Act could be denied if states failed to comply.

26. See Louise B. Russell, "Medical Care," in Joseph A. Pechman, ed., *Setting National Priorities: Agenda for the 1980s* (Brookings Institution, 1980), pp. 178–80.

The Nixon administration imposed wage and price controls on the health industry (from August 1971 to early 1974) as part of the economic stabilization program and left these controls in place for some months after those on the rest of the economy had been lifted. The controls interrupted the rapid growth of health expenditures, which averaged 8.4 percentage points more than the increase in the consumer price index for the five years preceding the freeze. As soon as controls were removed, expenditures shot up and rose an average of 11.1 percentage points a year more than the consumer price index through 1977.

Continued growth in expenditures led Presidents Ford and Carter to propose more fundamental changes. President Ford proposed limits on the rates of increase of reimbursement for hospitals and physicians under medicare. He also proposed billing patients for 10 percent of the costs of hospitalization. In return, coverage of very large bills would have been improved. Congress never considered these proposals seriously, and President Carter withdrew them.

Instead of trying to control the growth of medicare and medicaid alone, President Carter asked Congress to limit the growth of hospital expenditures in general. Such a limit would have reached not only the 75 percent of medicare and almost 40 percent of medicaid expenditures represented by hospital bills, but also private expenditures. Confronted with intense lobbying from the hospital and business sectors, Congress did not enact the Carter proposals, ostensibly because it wanted to see whether the so-called voluntary effort by hospitals to hold down costs would prove effective and obviate the need for federal regulation. The voluntary effort survived as long as the possibility of federal legislation seemed real, and held growth of hospital expenditures to only 3.4 percentage points more than the rise in the consumer price index from 1978 through 1979. Cost containment legislation was defeated definitively in 1979. By 1981 hospital expenditures were rising 8.4 percentage points more than other prices.

As the years of swelling medical expenditures have become decades, it has become clear that fundamental changes are necessary if expenditures are to be controlled. Effective cost control must alter the incentives of patients and providers, either through cost sharing or through some kind of budget limit. Cost sharing forces patients to consider whether the care they seek is worth

what it costs them.[27] Budget caps place a limit on the revenues of hospitals or other providers. Implementing a budget limit would require a considerable amount of regulatory interference, however. How should hospital limits vary with the facilities, case mix, and fixed costs of each hospital? Before increasing reliance on cost sharing, it would be necessary to decide whether payments should depend on the income or other characteristics of patients or providers. If beneficiaries were required to choose among alternative health insurance plans, it would be necessary to decide what protections to give patients, particularly the elderly, who may be too uninformed or bewildered to make sound judgments. These and other questions will have to be addressed in the competition plan that President Reagan has promised to present.

Some people hold out hopes that two other approaches to medical care—consumer education and scientific advances—may reduce costs, but these are at least as likely to raise costs as to lower them. Consumer education may deter people from seeking care for trivial or self-healing illnesses, but there is considerable risk that improved consumer education will increase demand for medical care, and, in any event, consumer education itself is costly. In the long run scientific advances may reduce the cost of health care. But though discovery of the fundamental causes of major life-threatening or disabling diseases may prevent premature deaths, it may also increase the frequency of slow and costly decline and the opportunities for costly medical intervention to improve the quality of life during these declining years.

1983 Budget Proposals

The health proposals in the 1983 budget reflect no unifying theme or philosophy other than the desire to hold down costs. They constitute a mélange of short-term measures to slow the growth of health outlays while the administration completes the design of its competitive strategy to slow the long-run rise in the cost of medical services. Because federal programs focus on

27. Results from a major health insurance study initiated by the Office of Economic Opportunity, continued by the Department of Health, Education, and Welfare (now the Department of Health and Human Services), and managed by the Rand Corporation show that the demand for health care is 14 percent greater when there is no cost sharing than when patients must bear 25 percent of the cost (up to $1,000 or a certain fraction of income, if less). See Joseph P. Newhouse and others, "Some Interim Results," p. 1501.

vulnerable populations, notably the aged, disabled, and poor, the reductions will cut the access of these groups to medical care, thus reversing a trend dominant since medicaid and medicare were enacted in 1965.

Proposed cuts in medicare total $2.5 billion in 1983. The most important would disallow reimbursement for 2 percent of every medicare hospital bill. Hospitals would be paid 98 percent of their incurred costs and would be prohibited from charging the patient the remainder. This proposal would reduce federal spending by an estimated $653 million in 1983. A large part of these costs would reappear as increases in private insurance, as hospitals tried to shift costs to other payers. An additional $306 million would be saved by requiring employers to provide the same insurance for workers aged sixty-five through sixty-nine as they offer to younger workers and by requiring such insurance to pay for care before medicare is billed. At present, private health insurers are usually charged for the medical costs of elderly workers only after medicare has paid for all covered services. Because medical care is more costly for elderly persons than for younger workers, and because most employers pay premiums that cover the actual cost of care for their employees, this provision may deter employment of older workers. The administration has eliminated professional standards review organizations on the ground that they do not save money, yet it claims $362 million in savings from the proposed expansion of utilization review by contractors who process medicare claims. A variety of smaller changes—shifting the update of physician fees from July to October (the next fiscal year), raising the deductible charged for coverage of physician bills to take account of inflation, reducing reimbursement for hospital-based radiologists and pathologists, delaying medicare coverage until the first full month of eligibility, and others—make up for the rest of the proposed $2.5 billion cut.

The administration also seeks to impose medicare payroll taxes on federal employees, most of whom acquire eligibility from nonfederal employment during their working lives. This proposal is a new, but justified, tax for these federal employees, yielding $619 million in 1983.

The list of proposed changes in medicaid is almost as long as the list for medicare, but the effects on access are likely to be

more serious, because medicaid benefits in many states are already far more restrictive than medicare benefits.[28] For example, medicaid in New Hampshire covers only twelve days of hospitalization a year; Tennessee and Kentucky cover fourteen days.[29] A 1975 survey of the Health Care Financing Administration found that medicaid fees were roughly three-quarters of those under medicare. Another survey found that medicaid reimbursements were 40 percent below normal fees.[30] Only half the people living in families with incomes below the official poverty line ($8,450 for a family of four in 1980) are eligible for medicaid.

The most important cuts in medicaid would reduce the federal matching rate for optional services and optional beneficiaries by three percentage points. All states offer some optional services; the most important, intermediate care, accounts for 27 percent of total medicaid expenditures.[31] In addition, the administration proposes to stop matching payments for the medicare part B premiums of those medicaid beneficiaries who are also eligible for medicare. In combination, these cuts would save $803 million in 1983 if adopted.

In addition, the administration would require medicaid patients to pay small sums for physician and hospital services; this cost sharing is projected to save $329 million. Reductions in eligibility for AFDC and SSI welfare payments, increased authority for states to collect nursing home costs from patients' relatives and estates, a cap on administrative costs, and other changes, are expected to bring net savings to almost $1.6 billion, a $2 billion saving for the federal government and a $0.4 billion increase in costs for the states. These proposals follow the administration's attempt last year to place a cap of 5 percent on the allowable annual increase in medicaid expenditures. Bipartisan congres-

28. One very important exception to this statement is the coverage of long-term care or nursing home services, which is far more generous under medicaid than under medicare. In fact, 41 percent of medical expenditures under medicaid in 1981 went for long-term care.

29. National Governors' Association, *Catalogue of State Medicaid Program Changes* (Washington, D.C.: NGA, 1981), pp. I-7–I-10.

30. Data provided by the Congressional Budget Office.

31. Intermediate care includes some costly nursing home care for the elderly. But it also permits physicians to discharge patients who are unable to care for themselves from hospitals to less costly nursing home beds.

sional rejection of that proposal last year suggests that the proposed cuts in medicaid will face considerable opposition.[32]

The most striking proposed change in medicaid, announced by President Reagan in the State of the Union Message, calls for federal assumption of full financial responsibility for medicaid in return for full assumption by the states of the costs of food stamps and AFDC. Unfortunately, no detailed plan existed at the time of the speech. It was not clear whether the enormous geographic variations in medicaid would be allowed to persist. The best guess is that some attempt will be made to set national standards, but it is unclear at what level these standards would be set and what protections would be afforded present beneficiaries. It is also unclear whether administration, now almost wholly in the hands of the states, would be federalized and, if so, what protections would be afforded state administrative employees. The Department of Health and Human Services began the task of answering these questions only after the president's speech in which the plan was unveiled.

Block Grants in Health Services

During the 1960s and 1970s successive administrations sought, and Congress enacted, many narrowly targeted grant programs to achieve specific health objectives. Almost as the programs were being created, these same administrations and Congresses recognized that their number bred confusion. As early as 1966 President Johnson sought to consolidate nine formula grants under the Partnership in Health Act. Last year President Reagan requested that twenty-six programs be lumped together in two block grants, one for preventive health and one for health services. The president sought simultaneously to reduce authorizations of these programs from $1.9 billion to $1.4 billion, a 25 percent cut in both preventive health and health services.

Congress gave the president some of what he sought. It created four block grants: in preventive health and health services; in

32. Instead of a cap, Congress merely cut its projections of the growth of medicaid expenditures in the budget resolution. Of greater significance, Congress authorized the negotiation by states of lower charges through restrictions on providers, capitation, and prospectively determined payments, instead of relying on cutbacks in eligibility and benefits. It is too early to know what savings will be achieved.

maternal and child health; in alcohol, drug abuse, and mental health (little changed from previous structure); and in primary care (which simply renamed the existing community health center program). Real expenditure on these programs was reduced by 28 percent. Of greater significance was the complete exclusion from the block grants of ten programs that the president had wanted to include, among which venereal disease control, family planning, and migrant health centers were the most visible and most controversial. But the real outlays for these programs were cut 19 percent. Given the financial difficulties that many states are experiencing, few are likely to find resources to make up for reduced federal spending.

For 1983 the administration again proposes to include in block grants the programs whose separate status Congress protected last year. In particular, the 1983 budget again seeks to fold migrant health and family planning into the primary care block grant. The maternal and child health block grant would absorb the nutrition program for women, infants, and children, now administered by the Department of Agriculture, and $284 million would be cut from the $934 million allocated to the program in 1982.

The Plan to Promote Competition

The administration's long-awaited proposals to promote competition in the medical system are expected later this year. The administration must decide whether to try to promote competition in private insurance, in medicaid and medicare, or in both. Application of the competitive strategy to private insurance raises very different issues from those relating to publicly financed programs.

If the administration decides to tackle private insurance, the legislation is expected to resemble the competition bills submitted in the past by, among others, former congressman David A. Stockman and former senator Richard S. Schweiker. These proposals sought to control the cost of health care by increasing the sensitivity of patients and providers to the costs of the services they seek and provide, primarily by requiring employers to offer several plans to their employees (ideally, one a health maintenance organization [HMO]—an organization of physicians that undertakes to provide or arrange for virtually all the medical care

required by the plan's subscribers in return for a fixed annual payment—and another with substantial cost sharing) and by setting a limit on health insurance premiums that employers may deduct as legitimate business expenses or that employees may exclude from taxable income.[33] These measures are designed to encourage workers to weigh the value of additional health benefits against other consumer goods. An employee who chooses a plan that costs less than the employer's contribution (which would be required to be uniform for each plan) would receive a rebate.

The chief obstacles to applying the competitive strategy to the private sector are political. Few groups involved in the delivery of health care stand to gain from an increase in competition; most, therefore, will fight it. Furthermore, slowing growth in the cost of private insurance has little direct effect on the federal budget.

Applying the competitive strategy to public programs would directly affect the budget and should have considerable political appeal, but it is not clear how to implement the strategy. In principle, the competitive strategy is simple enough: the government would offer beneficiaries vouchers for the purchase of private insurance, rather than automatically reimburse providers for a predetermined list of services. In practice, however, vouchers are an unknown quantity, and a host of questions must be resolved before they can be issued. A decision must be made on the value of the vouchers and on how the value should vary according to the characteristics of the beneficiary. No one knows how much coverage private insurers can offer for a payment equal to the current cost of medicare per enrollee, particularly because private insurers must incur selling costs that medicare is spared, and would be less able or less willing than medicare to bargain for or to impose low rates of hospital reimbursement.[34] If successful, the competitive strategy might offset these disadvantages in the long run; but in the short run costs might well increase, and even

33. Employers now may deduct without limit the cost of health insurance purchased for employees. Individuals are not required to include in adjusted gross income the value of such employer-financed health plans. In addition, individuals may deduct 50 percent of the health insurance premiums they pay, up to $150, and include additional premiums in health expenditures, which may be deducted to the extent that they exceed 3 percent of adjusted gross income.

34. Some estimates put the initial cost of vouchers offering the same benefits as medicare at 130 percent of current per capita medicare expenditures.

long-run success is speculative. Nor does anyone know how to handle nursing home care, which is seldom covered by private insurers but which accounts for 41 percent of the cost of medicaid.

Faced with such vexing problems, the task forces working on the administration's proposals may treat vouchers as experimental and permit enrollees the option of retaining basic medicare coverage. If this course is followed, a competition plan will have little effect on federal outlays; it may even increase them if high-cost patients remain with medicare while low-cost patients accept the voucher and purchase private insurance. Another course of action, reportedly under consideration, would require hospitals to accept payments fixed in advance under medicare (and conceivably under medicaid when it is federalized). Prospective reimbursement, however, is nothing other than a particular form of budget limit, much like those previously proposed by Presidents Ford and Carter.

In summary, the 1983 budget joins a long list of budget documents that have expressed concern over runaway medical costs and have taken only modest steps to curb them. The administration promises a new competitive strategy for dealing with this fundamental problem and attributes large savings to it in 1983 and later years, but the plan has not been worked out. The 1983 budget makes clear, however, that the twin problems of rising medical costs and federal deficits have terminated efforts to equalize access to medical services. Rather, efforts to curb federal health care expenditures are reviving the question whether the poor, the aged, and the disabled are to be assured health care on the same terms as others.

Education

The central question posed by the Reagan administration about education is whether there should continue to be an active federal role at all. Education programs rank high among the federal activities that the administration hopes to return to state and local control. This proposed shift would be accompanied by sharp reductions of federal financial support. Real budget authority for elementary, secondary, higher, and vocational education in 1983 will be 43 percent lower than in 1981 if Congress heeds President

Table 4-6. Total Federal Budget Authority for Education in Constant 1981 Dollars, Selected Fiscal Years, 1981–85

Billions of dollars

Item	1981	Projected 1982	1983	1985
Elementary, secondary, and vocational education	6.7	4.9	3.9	3.0
Higher education[a]	10.7	9.1	6.0	4.4
Total	17.4	14.0	9.9	7.3

Sources: *Budget of the United States Government, Fiscal Year 1983*, pp. 5-106–5-107; and table 4-8. Figures are rounded.

a. Includes Department of Education programs, Social Security benefits, GI Bill benefits, and health training.

Reagan's budget requests (see table 4-6). The budget projects a further 26 percent cut between 1983 and 1985.

Reductions of this magnitude cannot be construed as simple reforms to eliminate waste, fraud, and abuse. They challenge the assumptions and fundamental purposes that have guided federal policy in education for the last two decades. This year the debate should focus on whether those assumptions and purposes remain valid and important.

Although the history of federal involvement with education begins with the Northwest Ordinance Act of 1787, the rapid growth of federal support for education occurred during the last twenty-five years. The post-sputnik emphasis on improved scientific and technical training gave way during the 1960s and early 1970s to a concern for equality of educational opportunity. For the last decade the main objective of most federal elementary, secondary, and higher education programs has been to increase educational opportunities for those who have lacked them. The largest elementary and secondary programs serving this goal are title I of the Elementary and Secondary Education Act of 1965,[35] which provides extra money for school districts serving low-income, low-achieving youngsters, and the Education for All Handicapped Children Act of 1975, which requires a "free, appropriate education" for all children, regardless of handicap. In 1981 title I provided over $3 billion in compensatory education services for more than 5 million children in 14,000 school districts, and over $1 billion was appropriated to help states and localities

35. Now chapter 1 of the Education Consolidation and Improvement Act of 1981.

meet the costs of educating handicapped children. Other categorical programs, such as Indian education, bilingual education, follow-through, and the Emergency School Aid Act, assisted other needy children.

In higher education, the basic educational opportunity grant program (renamed Pell grants after Senator Claiborne Pell of Rhode Island) was enacted in 1972 to assist students from low-income families pay for college. Pell grants, together with other grant, loan, and work-study programs, contributed over $6 billion to the support of low- and middle-income students in 1981. Social security provided nearly $2 billion to eligible families on behalf of students over eighteen, and the GI Bill contributed more than $1.5 billion in educational benefits to veterans. Enactment of the education amendments of 1980 reaffirmed the federal partnership with state, local, and private agencies in supporting equal educational opportunity for all citizens. It is this commitment that the Reagan administration has cast in doubt.

Elementary and Secondary Education

Table 4-7 presents the budget authority requested for the principal elementary and secondary programs in 1983 and projections for 1985.

The Education Consolidation and Improvement Act of 1981 rewrote the Elementary and Secondary Education Act of 1965 by combining twenty-nine categorical programs into a state education block grant (chapter 2, ECIA). It retained compensatory education as a separate program (chapter 1, ECIA), but relaxed the requirements governing state and local allocation of funds. When added to the actions taken last year, the proposed 1983 cuts would reduce real budget authority for compensatory education by more than 45 percent from 1981 and block grants by 38 percent. This year the administration proposes two further consolidations, one for programs serving the handicapped and the other for vocational and adult education, with increased state and local discretion in the use of funds.

The administration justifies the proposed cuts in budget authority by noting the "overall need for fiscal restraint" and by stating that the cuts "represent lower priorities for Federal funding

Table 4-7. Federal Budget Authority for Elementary, Secondary, and Vocational Education in Constant 1981 Dollars, Selected Fiscal Years, 1981–85

Billions of dollars

Item	1981	Projected		
		1982	1983	1985
Compensatory education	3.1	2.3	1.7	1.2
State education block grant	0.6	0.4	0.4	0.2
Indian education	0.4	0.3	0.3	0.2
Impact aid	0.7	0.4	0.3	0.2
Education for the handicapped	1.0[a]	0.7[a]	0.7[b]	0.7[b]
Vocational and adult education	0.8[a]	0.6[a]	0.4[b]	0.4[b]
Other	0.2	0.1	0.1	0.1
Total	6.7[c]	4.9	3.9	3.0

Source: *Budget of the United States Government, Fiscal Year 1983*, p. 5-106. Figures are rounded.

a. Existing law.

b. Proposed legislation.

c. The Carter administration had estimated budget authority in fiscal 1981 at $7.3 billion. The main differences are in vocational and adult education ($139 million), education for the handicapped ($50 million), and other ($307 million).

than other activities."[36] The administration also claims that increased flexibility in the use of funds at the state and local level will make it possible for the neediest children to be served despite the sizable cut in resources. This assertion may have some validity, but increased efficiency will not offset a 43 percent cut in real resources over two years. Instead, fewer instructional services will be provided to a smaller number of students.

The administration candidly acknowledges that it does not place much value on the expenditure of federal revenues for the purposes served by these programs, preferring instead to turn back these responsibilities to the states. Some states may take up the responsibilities that the Reagan administration proposes to abandon. But the same incentives that discourage states from providing income assistance to the poor will deter states and, especially, municipalities and school districts from fully replacing federal assistance. The decision to accept or to reject the administration's proposals must address the question of the degree to which a just society will permit large differences in educational opportunities for its citizens.

36. Office of Management and Budget, *Major Themes and Additional Budget Details, Fiscal Year 1983*, p. 152.

Equity, however, cannot be the sole criterion for judging the proposed budget cuts. If programs such as title I did not produce gains in educational achievement, then the funds should be cut, and their loss would have little effect on educational opportunity. But a recent comprehensive evaluation of title I found statistically significant gains in achievement by title I students relative to control groups.[37] Educational gains were made in mathematics in all six primary grades and in reading in grades one through three.

The more difficult question is whether the increased achievement of 15 to 20 percent per student in the primary grades is worth the roughly $460 spent per child from title I funds.[38] Until more is known about the subsequent education and employment of students helped by title I, it is not possible to compare benefits with costs. What is clear is that the proposed real cut in title I budget authority of 45 percent between 1981 and 1983 will reduce the number of children receiving compensatory education by approximately 1 million and reduce assistance to those who remain in the program.[39]

Most federal support for handicapped students comes from the state grants authorized by the Education for All Handicapped Children Act, but in 1982 about $360 million also came from compensatory education for state-operated programs (chapter 1, ECIA), from preschool incentive grants, and from other discretionary programs. The administration proposes to consolidate these programs and to provide block grants to the states, which will allow increased flexibility in the use of the funds.[40] The $846 million requested for the consolidated program is roughly half what would be required in 1983 to maintain the federal share at 12

37. Launor F. Carter, *The Sustaining Effects Study: An Interim Report*, prepared for the Department of Education, Office of Program Evaluation (Santa Monica: System Development Corporation, 1980).

38. Janice Anderson, "Executive Summary, Study of the Sustaining Effects of Compensatory Education," memorandum, Department of Education, Office of Planning, Budget, and Evaluation, November 1981, p. 17.

39. The administration estimates that 4.3 million children can be served in fiscal 1983 if states can lower costs per student to $400.

40. The Carter administration early considered a comparable consolidation, but dropped it when political opposition became evident. Constituent groups argued that more federal support for handicapped children would be forthcoming from several programs than from one.

percent of the national average expenditure per pupil, the level achieved in 1981.

The administration also proposes to consolidate vocational and adult education and to cut real spending between 1981 and 1983 by 50 percent. Previous administrations, as well as the Congressional Budget Office, have viewed vocational education as a likely candidate for budget cuts because it is assumed that most states would make up the 10 percent of total costs represented by the federal contribution. Roughly half the federal support is unrestricted, while the other half is bound by various set-asides for disadvantaged students and for activities of particular federal interest. Protected groups are likely to bear a disproportionate share of the cuts if the proposed block grant eliminates the set-asides.

The Reagan administration is proposing to continue the policies for education it established last year—consolidation, large budget cuts, and reduced federal influence on state and local decision-making. A logical extension of these policies would be the eventual elimination of any federal involvement in elementary and secondary education, for as budgets shrink and the focus on target populations weakens, the rationale for federal participation is lost. In 1981 Congress went along with the president with little debate as legislative changes were made under the pressure of the budget reconciliation procedure. This year Congress will have a second chance to consider whether the older purposes are still valid and whether new national needs in education are emerging that may require federal support.

As stated earlier, for at least the last decade, the dominant rationale for federal support of elementary, secondary, and higher education has been to equalize educational opportunity. Federal programs were created because schools and colleges, financed and governed by local, state, and private agencies, were not meeting this objective. Federal financial support enriched the education of low-income, low-achieving children in primary and secondary schools and provided aid for low-income students who could not otherwise have paid for college. These programs have not met all the early expectations held for them, and many need reform. Now, because of the president's budget, Congress must address the question whether to slash these programs as no longer

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affordable luxuries and return essentially all responsibility for education to state, local, and private sources. Fewer federal dollars and increased state and local discretion are almost certain to reduce spending for education in many states and to diminish opportunity for low-income or disadvantaged groups.

Higher Education

The 1983 budget continues the policy begun last year of reducing both the number of college and university students receiving federal assistance and the aid that the remaining beneficiaries will receive (see table 4-8).[41] Most financial aid to students comes through need-based grants or subsidized loans or through such entitlements as the GI bill and social security student benefits. Between 1981 and 1983 the administration proposes to cut these programs by 44 percent in real terms. Additional reductions are scheduled for later years. If the president's program is adopted, the number of awards, other than guaranteed student loans and health training grants, will drop from an estimated 6.1 million to 3.3 million between 1981 and 1983, a decline of nearly 46 percent. An unduplicated count of student recipients does not exist. Nor is it known how many students would be forced by the cuts to withdraw or to cancel plans to attend college, how many would be forced to enroll part-time rather than full-time, and how many would shift from higher-priced to lower-priced colleges. Some of the students whose aid is cut off under these programs might receive aid under the vestiges of other programs. The fate of individual colleges and universities would be strongly affected as well, for the cuts coincide with the decline in the eighteen- through twenty-one-year-old population, and would thereby accentuate the anticipated drop in enrollments.[42]

The main changes proposed by the 1983 budget for higher education are (1) a sharp cut in Pell grants that would reduce the number of students receiving this form of need-based aid by nearly 1 million, and a decline of 16 percent in the real value of the maximum grant between 1981 and 1983; (2) the elimination of

41. Excluded are support for research conducted in universities and tax expenditures that benefit higher education.

42. Because most of the grant programs are forward funded, the effect of cuts in budget authority proposed for 1983 would not be felt until the 1983–84 academic year.

Table 4-8. Federal Budget Authority for Higher Education in Constant 1981 Dollars, and Number of Students Aided, Selected Fiscal Years, 1981–85

Awards in billions of dollars; students aided in thousands

Item	*1981*	*1982*[a]	*1983*	*1985*
Budget authority				
Pell grants	2.3	2.1	1.2	0.8
Supplementary educational opportunity grants	0.4	0.3	0.0	0.0
National defense student loans	0.2	0.2	0.0	0.0
College work-study program	0.6	0.5	0.4	0.3
State student incentive grants	0.1	0.1	0.0	0.0
Guaranteed student loans[b]	2.5	2.6[c]	2.2	2.0
Health training	0.7	0.4	0.3	0.3
General institutional assistance and other	0.6	0.5	0.4	0.4
Social security	1.9	1.3	0.7	0.1
GI Bill benefits[d]	1.5	1.1	0.9	0.5
Total	10.7	9.1	6.0	4.4
Students aided				
Pell grants	2,770	2,400	1,800	n.a.
Supplementary educational opportunity grants	615	463	0	0
National defense student loans[e]	266	256	0	0
College work-study	916	880	666	n.a.
State student incentive grants	300	296	0	0
Guaranteed student loans[b]	3,500	2,900	2,800	n.a.
Parent loans	0	943	1,400	n.a.
Social security[f]	590	610	316	50
GI Bill benefits[g]	681	585	492	331

Sources: *Budget of the United States Government, Fiscal Year 1983*, p. 5-107; OMB, *Major Themes and Additional Budget Details, Fiscal Year 1983*, pp. 74–75; and data provided by the Social Security Administration, Veterans Administration, and the American Council on Education. Figures are rounded.

n.a. Not available.

a. Based on funding levels in the fiscal 1982 continuing resolution.

b. For 1982 and after, figures are based on proposed legislation.

c. An additional $300 million may be required to cover the costs of this program.

d. For veterans in higher education only. Figures are awards offset by receipts.

e. Students aided from new capital contributions only; students aided from repayments of previous loans are not included.

f. Figures are for September and are generally lower than figures for months later in the academic year.

g. For veterans in higher education only.

supplemental educational opportunity grants, national direct student loans, and the state student incentive grant programs, all of particular importance to private colleges and universities; (3) reduced subsidies for the guaranteed student loan program and the exclusion of graduate and professional students from borrowing under it; (4) the beginning of the four-year phaseout of social security student benefits enacted last year on the ground that

needy recipients, 72 percent of whom are from families poor enough to qualify for need-based grants, could turn instead to grants and loans; and (5) cuts in health professions training programs of nearly 75 percent in real terms from the 1981 figure. No new health professions student loans would be made, nursing student loans and exceptional need scholarships would be eliminated, the national health service corps would receive no new starts, nursing programs would be cut from $50 million to $12.5 million, and no subsidies for physician education would be provided.

The proposed cut in Pell grants would more than reverse the expansion of aid to middle-income students enacted in 1978. The Middle Income Student Assistance Act extended aid to students from families with incomes up to $25,000; the current proposal could limit grants to families with incomes of $15,000 or less, depending on the formula adopted. When the program was created in 1972, the maximum grant was $1,400; after adjustment for inflation, the value of the $1,600 maximum award proposed for 1983 is half that initial award. With the average cost of a year in college currently at $5,500, even the maximum Pell grant available to the neediest students covers less than 30 percent of direct costs.

Costs of the guaranteed student loan program have soared in recent years as the number of borrowers has increased and climbing interest rates have driven up the interest subsidy. Proposals this year to curtail costs include increasing from 5 to 10 percent the fee paid to banks for originating loans, applying a needs test to every borrower, charging a market rate of interest after the second year of repayment, and eliminating graduate and professional student borrowing. Graduate students would be allowed to borrow under a new auxiliary loan program that carries a higher interest rate (14 percent as opposed to 9 percent) and no in-school interest subsidy (the loan enters repayment sixty days after borrowing). Because of the repayment provisions, many banks may be unwilling to lend to graduate students under this program, which operates now in less than half the states.[43]

The need to limit costs in the guaranteed student loan program is clear, but the flat exclusion of graduate students from the

43. Efforts are being made to secure participation of lenders in all states.

program would simply cut off in mid-course an estimated 600,000 graduate and professional students at the very time that there is a perceived shortage of scientists and engineers. Measures to reduce the interest subsidy, while preserving eligibility for graduate students, would reduce use of the program, lower costs, and would preserve options for students who need to borrow to attend a university.

How would the various sectors of higher education fare under the Reagan budget if enacted in its current form? Private colleges would be hit particularly hard, since their students have come increasingly to depend on federal student aid to help cover tuition. The National Institute of Independent Colleges and Universities has estimated that the 1.1 million students receiving aid at private colleges and universities in 1980–81 would lose about $1.3 billion in federal aid, leaving 500,000 students unable to cover the cost of an independent college in 1983–84.[44] Graduate and professional schools would also suffer large drops in enrollments if borrowing under the guaranteed student loan program is prohibited. Public universities would be affected by cuts in both grants and loans, while community colleges would be affected most by the cuts in Pell grants. Bankruptcies and closures of small, nonselective, private liberal arts colleges would increase. Community colleges alone might gain, as students who lack resources shift to relatively inexpensive institutions. Access to elite institutions, both at the undergraduate and professional levels, by students who are not wealthy will be curtailed. If most of the reductions proposed in the 1983 budget are adopted, the proportion of the generation of students nearing college age that will be able to acquire a higher education will be smaller than it has been in recent generations.

In defining the federal role in education, Congress may also consider issues relating to the quality of education. How can brighter and more capable people be lured into teaching? How can links be established and strengthened between the school curriculum and the increasingly technical employment market? At the college and university level, concerns are growing about the obsolescence and deterioration of research equipment, library

44. Virginia Hodgkinson, "The Impact of the President's Budget Proposals upon Students Attending Independent Colleges and Universities" (Washington, D.C.: National Institute of Independent Colleges and Universities, March 1982).

collections, and the physical plant, as well as with the vitality of an aging faculty.

In short, federal educational policy today must address two central questions. Is the goal of equality of educational opportunity still a national concern? And should the national government help states and localities to achieve and maintain high-quality education from primary through professional school? Whether Congress agrees with the administration's negative answers to both questions remains to be seen.

Employment and Training Programs

The federal government supports a variety of locally administered manpower training programs under the Comprehensive Employment and Training Act (CETA).[45] In 1981 President Reagan proposed to eliminate public service employment, and Congress agreed. Because of this change and a large drop in training, real expenditures on employment and training programs will fall from $7.9 billion in 1981 to $2.4 billion in 1983.

CETA is due for reauthorization this year, and the president has proposed further cuts in his 1983 budget. He also seeks to eliminate the work incentive program that provides training and jobs for people otherwise dependent on welfare; in its place states would be empowered to require welfare recipients to take special jobs under community work and training programs. He also proposes to reduce sharply the size of the state-federal employment service.

COMPREHENSIVE EMPLOYMENT AND TRAINING. The details of the administration's CETA proposal are contained in a reauthorization plan recently submitted to Congress. Most of CETA's titles will be consolidated into a single block grant to states to pay for the training of welfare recipients and economically disadvantaged out-of-school youths. The proposed plan would permit states to spend a small fraction of the federal grant on other disadvantaged groups. Presumably states would distribute the funds to local

45. CETA provides public service jobs for economically disadvantaged adults in two programs, one designed to handle cyclical unemployment, the other for structural unemployment. Titles II-A, II-B, and II-C give workers training and work experience. Programs for migrant farm workers and native Americans are grouped under Title III. Title IV gives on-the-job work experience for unemployed youth; the Job Corps is administered under this title. Title VIII created the young adult conservation corps.

authorities similar to existing CETA prime sponsors, who would provide training services or contract with others to provide them. States and localities would be prohibited from spending federal funds on public service employment, training stipends, or "work experience" programs. Thus enrollees in local programs would be restricted primarily to on-the-job training with private employers or to formal classroom training in training institutions. A major feature of the proposal is to give substantial control in design and control of the training programs to private business. Real outlays on CETA programs would decline from $8 billion in 1981 to $1.9 billion in 1983.

These changes depart radically from past practice. In 1980 work experience and public service employment constituted two-thirds of the service years provided under CETA. Training stipends, usually set at the minimum wage, have accounted for about half the cost of classroom training to CETA enrollees. Many present CETA participants who are neither young nor welfare recipients would be prevented from participating in training under the president's 1983 proposals.

Contrary to popular belief, manpower programs have been effective in improving enrollees' earnings, though frequently by modest amounts. An exhaustive recent study concludes that four of CETA's five basic employment and training programs—including public service employment—succeeded in raising the post-program earnings of enrollees by 6 to 18 percent.[46] Only CETA's work experience programs failed to raise enrollee earnings. Questions remain about whether the gains in earnings justify the costs. But it does appear that these programs have made progress toward their main objective. In addition, public service employment earnings and training stipends in some measure replace welfare payments on which beneficiaries otherwise would be forced to depend; and public service employees and work experience trainees often provide valued local services for financially hard-pressed counties and municipalities.

WORK INCENTIVE PROGRAM. This program provides manpower counseling and training for AFDC recipients. Participation is

46. Westat, Inc., *Impact on 1977 Earnings of New FY1976 CETA Enrollees in Selected Program Activities*, Employment and Training Administration, Office of Policy, Evaluation, and Research (ETA, 1980).

mandatory for most able-bodied adult AFDC recipients without very young children, and is voluntary for others. The president proposes to eliminate this $381 million program in 1983. The budget states that the work incentive program will be unnecessary in 1983 once states have set up mandated community work experience or "workfare" programs. Presumably the training that would otherwise have been provided by the federal program would then be provided in these community public service projects, where AFDC recipients would be required to work off their welfare grants. Past experience suggests that little if any training would be given on state or local work projects.[47] Although such social services as child care will be curtailed with the elimination of the work incentive program, the effects on AFDC recipients may be mitigated by the concentration on them of such CETA training benefits as remain.

EMPLOYMENT SERVICE. The employment service provides labor market information, especially for low-wage workers who are not well served by private alternatives. Since the 1930s the employment service has told workers and potential workers about available jobs and has sought to make the labor market operate more efficiently by reducing frictional unemployment. Because higher-wage workers tend to find employment through other means, the employment service disproportionately serves low-wage workers and their employers.

The administration proposes to reduce real federal outlays for this service from $804 million in 1981 to $511 million in 1982, and to $426 million in 1983 and subsequent years, a cut of nearly half. The employment service recently has had low placement rates, but there is some evidence that it has nonetheless shortened the duration of unemployment for people it served.[48] What makes this proposed budget reduction puzzling is that job referral assistance is one of the cheapest methods of helping disadvantaged workers

47. See Ketron, Inc., *Food Stamp Workfare Demonstration Project: Interim Report on the Short-Term Impact of the Program* (Wayne, Pa.: Ketron, 1981), pp. 28–31; Wellington Webb and Carla Bodaghi, "Utah Work Experience and Training Assessment," Department of Health, Education, and Welfare, Region 8 (Denver, Colorado: HEW, 1978); and Barry Friedman and others, *An Evaluation of the Massachusetts Work Experience Program* (Center for Employment and Income Studies, Brandeis University, 1980).

48. Terry Johnson and others, *A Pilot Evaluation of the Impact of the U.S. Employment Service* (Menlo Park, California: SRI International, 1979).

to raise their earnings. Since the administration proposes to reduce or to abandon such assistance as training and public service employment, an increase in efforts to make the private labor market work more effectively would seem prudent. The employment service is the most important existing state-federal instrument for accomplishing this goal.

EFFECTS OF THE CHANGES. Because benefits from the work incentive and CETA programs accrue largely to the unemployed and economically disadvantaged, the population that suffers most from the cutbacks is easy to identify. It is the same population hurt most by recent and proposed changes in means-tested transfer programs, namely low-income families with a potential earner.

Taken in combination with the proposed changes in transfer programs, the scheduled reductions in manpower programs appear to represent a systematic withdrawal of both income assistance and manpower services from the working poor in the midst of the most serious economic decline since the 1930s.

Conclusion

Emboldened by his success in securing approval for most of the program he proposed in 1981, President Reagan is returning for even larger cuts in domestic programs than he obtained last year. These reductions do more than extend last year's program. Most of the cuts enacted in 1981 reduced the size of the programs they affected but did not change their basic structure. Last year the president persuaded Congress that many programs could be trimmed without undermining their capacity to achieve their basic goals. Furthermore, he assured Congress and the American people that certain programs, basic to economic security, would be preserved as a "social safety net."

Proposals advanced after his budget amendments last year together with the 1983 budget make clear that President Reagan intends to eliminate major social programs and shrink even those that constitute the safety net. In some cases federal spending is to be curtailed enough to require a change in traditional objectives. In others the federal government will withdraw completely and leave to states the decision about whether any services at all are to be provided. The 1983 budget for domestic programs must be

viewed not merely as one element in an overall economic plan, but as the boldest and most controversial attempt in fifty years to roll back the place of the federal government as a guarantor of equal opportunity and provider of social services.

CQ On The Issues

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SPACE SHUTTLE: NASA VERSUS DOMESTIC PRIORITIES

President Nixon's announcement on Jan. 5, 1972, that he favored giving the National Aeronautics and Space Administration (NASA) $5.5-billion over the next six years to develop a space shuttle produced a mixed reaction from Congress.

Supporters of the space shuttle hailed the decision as a milestone in America's space program while critics termed the program wasteful and an example of misplaced priorities.

Plans for the space shuttle call for a reusable two-stage vehicle consisting of a booster and an orbiter.

The orbiter would carry a two-man crew and two passengers with the capability—when modified—of carrying six to 12 passengers. It would be able to remain in space for up to 30 days.

NASA hopes to schedule the first manned space shuttle flight by April 1978 and expects the space shuttle to be entirely operational by the end of the decade.

In a statement announcing his support for the space shuttle, Nixon said: "It will revolutionize transportation into near space, by routinizing it. It will take the astronomical costs out of astronautics."

Congressional critics of the space shuttle question its usefulness and are planning a campaign to keep the shuttle from being built.

References. *State of the Union address (science and technology section), Weekly Report p. 128; fiscal 1972 NASA authorization, 1971 Weekly Report p. 1478, 1265; fiscal 1971 NASA authorization, 1970 Almanac p. 200.*

The Issues

The dispute over the space shuttle involves three major issues.

Manned Space Program. Dr. James C. Fletcher, the NASA administrator, stated in a Jan. 5 press conference: "The shuttle is the only meaningful new manned space program which can be accomplished on a modest budget." Critics of the shuttle argued that the future U.S. space effort should concentrate on unmanned flights. Sen. Walter F. Mondale (D Minn.) commented Jan. 16 in a television interview on *Issues and Answers*: "I think that a space program of $2- to $3-billion a year, largely an unmanned, instrument flight, but also in some manned flight, could give us a fully sophisticated and very useful program."

Space vs. Domestic Needs. Supporters of the space shuttle described it as a logical extension of U.S. efforts in space and important for technological advancement. Sen. Edward J. Gurney (R Fla.) commented Jan. 16 on *Issues and Answers*: "It is extremely important to the United States to have a continuing and viable space program because technology, of course, is the strength of any great industrial nation.... We must continue in space and this is the next sensible and logical step."

Opponents criticized Nixon for requesting funds for the program instead of for domestic needs. Sen. William Proxmire (D Wis.) Jan. 8 in a press release called the decision "an outrageous distortion of budgetary priorities." He added, "...the President has chosen the space shuttle over money for schools, health, housing, mass transit, open space, environmental needs or other vital programs."

NASA's Future. Supporters of the space shuttle say NASA's future and its political and technological prestige are riding on the debate. Opponents confirm this, arguing that if they can stop the shuttle, NASA will have to be content to operate without expensive projects.

Manned Space Program

The manned space flight program which involved the Mercury, Gemini, Apollo and Skylab projects consumed the largest percentage of NASA's research and development funds since the U.S. space program began.

The prestige of NASA and the technological eminence of the United States climbed in the international community on July 20, 1969, when astronauts Neil A. Armstrong and Edwin E. Aldrin Jr. landed on the moon.

The moon landing also created problems for the manned space program. One problem involved the old debate over the future of the space program and national priorities. The opinions of some of the space program's staunchest supporters wavered. Sen. Clinton P. Anderson (D N.M.), chairman of the Senate Aeronautical and Space Sciences Committee, had commented in 1971 in an interview with Congressional Quarterly: "I was very much in favor of putting a man on the moon, but I don't see the second step. Do we go to Jupiter or Mars? It is a very expensive process and I don't think that we can afford it now."

The second problem posed by the moon landing was the creation of a "what a tough act to follow" attitude on the part of some space planners.

A report entitled "The Post-Apollo Space Program: Directions for the Future" presented to the President on Sept. 15, 1969, stated that "manned exploration of the planets is the most challenging...of the many long-range goals available to the nation." The report suggested setting a date for a manned Mars landing.

Another plan advanced by advocates of manned space flight for the 1970s involved the development of a reusable space shuttle and a space station. Dale D. Myers, NASA's associate administrator for manned space flight, told the House Science and Astronautics Committee in February 1970 that the United States must continue to have a strong manned space flight program to promote new technology and to maintain its competitive position.

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The Shuttle Mission
1 Booster and orbiter stages launched
2 Booster and orbiter separate
3 Booster returns to earth (two designs are under consideration; one would be recovered and reused while the second would be expendable)
4 Orbiter proceeds into earth orbit
5 Orbiter re-enters earth atmosphere
6 Orbiter lands horizontally
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Chapman

He strongly endorsed the space shuttle as a project with applicability for scientific and military purposes.

The Apollo program will be concluded with the launchings of Apollo 16 and 17 in 1972. The Skylab experimental space station program will be concluded in 1973. Without the shuttle, the United States will have no program of manned space flight after 1973. Budgetary restrictions have ruled out construction of a space station, a NASA spokesman said. Space planners are also aware that programs for the manned exploration of Mars would be far too costly to get through Congress in light of the difficulties that the space shuttle is facing.

Unmanned Programs. Critics of the space shuttle contended that the program was being advanced at the expense of unmanned programs. Mondale, a leading critic of the space shuttle, repeatedly expressed this fear:

"Virtually all of the useful things we have gotten out of space; communications, earth surveillance, weather stations, navigation, the technology of instrumentation and miniaturization, most of this has come about through unmanned instrumented flight." (Jan. 16, on *Issues and Answers*)

Shortly after the fiscal 1973 budget was released, Mondale stated in a Jan. 25 press release: "The FY 1973 budget reveals that in order to absorb the gigantic costs of the shuttle, NASA is cutting the heart out of vital scientific programs to explore the mysteries of the universe with unmanned space missions. The grand tour (unmanned) of the solar system—long advocated by space scientists—is one major casualty of the wasteful decision to build the shuttle. And because of the shuttle, NASA is delaying the launching of two orbiting solar observatories."

Shuttle vs. Domestic Priorities

Supporters of the shuttle point to the reduced launching costs because of the shuttle's reusable features and the scientific benefits to be derived from the shuttle's mobility. They argue that the nation's space program has been cut back far enough because of an emphasis on social priorities.

Opponents of the shuttle contend it is wrong to commit the nation to another expensive space program when many problems need to be solved on earth. They emphasize that with more money needed for education, housing and mass transit, the space program should have

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Presidential Politics and the Space Shuttle

The space shuttle has emerged as an issue in presidential politics during discussions of national priorities and because of its importance as an economic issue in Florida, which holds the nation's second presidential primary March 14.

Statements on the space shuttle by President Nixon and five of the announced Democratic presidential contenders follow:

Nixon. When he announced the space shuttle development plans Jan. 5, Nixon said: "...commitment to the space shuttle program is the next right step for America to take, in moving out from our present beachhead in the sky to achieve a real working presence in space —because the space shuttle will give us routine access to space by sharply reducing costs in dollars and preparation time."

Humphrey. In a position paper, Sen. Hubert H. Humphrey (D Minn.) said: "...three essential arguments in favor of the space shuttle have convinced me of the value of the program...the space shuttle will be economically efficient...have a tremendous impact on the future exploration of space...mean that many of those who are now unemployed...will be reemployed." Humphrey was not a member of the Senate at the time of the vote on the fiscal 1971 NASA authorization and was recorded as not voting on the agency's fiscal 1972 authorization.

Jackson. Sen. Henry M. Jackson (D Wash.) prepared an article for *The Machinist*, a magazine published by the International Association of Machinists, in which he wrote: "...the space shuttle is important to America...vital to science...important to working men and women...a good investment which will return its cost to the people many times over." Jackson voted against amendments to delete funds for the shuttle from the fiscal 1971 and 1972 NASA authorizations.

Lindsay. A spokesman for New York Mayor John V. Lindsay, said Lindsay believes the space shuttle is too costly a project in view of the country's pressing domestic needs. Lindsay favors a smaller and less expensive unmanned space exploration program.

McGovern. Sen. George McGovern (D S.D.) supported an amendment to delete funds for the shuttle from the NASA authorization in fiscal 1971 and announced for a similar amendment in fiscal 1972. Spokesmen at McGovern's Washington campaign headquarters and Senate office told Congressional Quarterly McGovern opposed development of the space shuttle.

Muskie. Sen. Edmund S. Muskie (D Maine) stated Jan. 28 in Miami, Fla.: "...in terms of current priorities and demands upon our national resources, I don't think it (space shuttle) has as high a priority as others such as the subject we are discussing here today (the environment)." Muskie voted for amendments to delete funds for the shuttle from the fiscal 1971 and 1972 NASA authorizations.

a lower priority. The opponents express the fear that the program's actual cost has been understated.

Both sides have used space shuttle cost figures to reinforce their support or opposition to the program.

Benefits. NASA estimated the research and development costs for the space shuttle at $5.5-billion over the next six years (fiscal 1973-78). Some $1-billion was added to that figure by NASA to serve as an increase allowance to cover unforeseen research and development problems. Two complete shuttles would be produced during the research and development stage.

NASA estimated that an additional $1.5-billion would be needed at a minimum for the procurement of three additional shuttles, facilities to launch and land the shuttles and extra equipment. The total investment cost of the shuttle is $7-billion and $8-billion when the contingency fund is included, according to NASA.

NASA stated that the shuttle could be developed and several other programs in space science applications and aeronautics maintained if NASA's total budget authority remained at $3.4-billion through the 1970s. *(NASA funding, illustration p. 439)*

Nixon's budget request for the space shuttle in fiscal 1973 was $200-million. NASA estimated that the highest level of funding for the shuttle would be $1.3-billion in fiscal 1976.

To make room for the cost of the shuttle, NASA canceled other programs. The canceled programs included the grand tour (an unmanned mission to the outer planets scheduled for the late 1970's) and the NERVA program to develop a nuclear rocket engine. The grand tour, estimated to cost $700-million, was replaced with a $7-million mission to Jupiter and perhaps Saturn. The NERVA project, on which $1.4-billion had already been spent, was canceled outright.

Once in use, the space shuttle would replace all the current launch rockets used to thrust satellites into space.

Cost Effectiveness Study. A NASA cost effectiveness study based on slightly more than 40 satellite launchings per year, the yearly average of the U.S. unmanned program over the last eight years, showed that the shuttle was economically feasible. It assumed NASA, the Defense Department and other agencies would fly 500 shuttle missions over a 12-year period between 1979 and 1990.

The study estimated that conventional launchings over the 12-year period using rockets would cost $11-billion. The total shuttle launching costs would be $5.8-billion or $5.2-billion less than the conventional method.

Payload development and procurement costs for the 500 missions during the 12-year period would be $29.8-billion for conventional launches. The comparable

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figure for the shuttle was set at $22.6-billion. The study said that the $7.2-billion savings with the shuttle system was due to payload reusability, design simplification and lower risk factors.

The study concluded that the shuttle would save $12.4-billion under the cost of conventional launching in the 1979-1990 period.

Priorities. Mondale, one of the most vigorous critics of the space shuttle, expressed anger at Nixon's veto of a $2.1-billion child care bill at the end of the first session of the 92nd Congress. After the President announced that the nation would develop a space shuttle, Mondale compared the decision and the child care veto in a Jan. 6 press release:

"Typically, this administration can squander $6.5-billion to fly four people in orbit, while it refuses to invest less than one third that amount to provide desperately needed day care and development programs for millions of pre-school children...."

Proxmire in a Jan. 8 press release calling the shuttle "the last thing we need at this time" stated: "The President has clearly re-ordered our priorities. But he has re-ordered them in the wrong way."

Critics' Cost Estimates. Critics of the space shuttle said more expense is involved than the research and development costs. They set out to attack NASA's $5.5-billion to $6.5-billion research and development estimate and to emphasize long-range program costs.

Mondale stated in a Jan. 25 press release: "The briefings and materials on NASA's FY 1973 budget have exposed two myths concerning the proposed space shuttle.

"The first myth was that the shuttle would 'only' cost $5.5-6.5-billion. But now, NASA admits that the shuttle's cost over a 10-year period of operation will be $10-14-billion—more than double the figure ballyhooed by NASA and the Nixon administration over the past several weeks.

"But even that figure is deceptive....

"It does not include the cost of the shuttle's payloads, which will add another $20-28-billion to the shuttle's total costs....

"...we are really talking about a massive effort in space which could cost anywhere from $35- to $52-billion.

"The second myth has been that opponents of the shuttle are anti-space exploration...."

NASA's Future

More than NASA's pride is riding on the space shuttle. For the ailing aerospace industry, the space shuttle represents one of the few chances many companies have to obtain a lucrative government contract in a drastically reduced space program.

President Nixon emphasized that the space shuttle would have a great impact on the aerospace industry.

Dr. Fletcher added: "Perhaps the greatest benefit may very well come in making good use of the professional skills and professional employees, some of whom are wondering about where the aerospace world is going. I think it is proper to say at this time that we anticipate that at its peak, the direct employment on the space shuttle will be of the order of 50,000 individuals."

A NASA spokesman explained that the 50,000 jobs meant that 108,000 persons would be employed on NASA contracts in fiscal 1973. In fiscal 1971, 112,000 workers were employed on NASA contracts. With the conclusion of the Apollo program in 1972 and the Skylab in 1973, contractor employment on NASA projects would drop to 50,000 without the space shuttle, according to NASA. Employment on NASA projects was highest at the peak of the Apollo program in fiscal 1966 when 390,000 persons were employed by aerospace contractors.

Opponents of the space shuttle criticized NASA for planning a "senseless extravaganza" to perpetuate its own interests.

Mondale issued a press release on Jan. 6 which read: "As with so many other expensive weapons and gadgets, the construction of the space shuttle has more to do with perpetuation of bureaucratic interests and the politics of government contracting than with the authentic needs of our nation."

Proxmire in a Jan. 8 release said: "The main rationale for the shuttle is that it will keep our space program going. It will keep the NASA technicians occupied. It will keep the aerospace industry happy."

Congressional Views

Sen. Edward J. Gurney (R Fla.): "We are in space to stay," Gurney said in an interview Jan. 28. "The space shuttle is an improved and reusable vehicle to carry both space satellites and men into earth orbit," he added.

Gurney explained that the shuttle booster would replace all of the launch rockets currently in use. It would be used to launch communications, weather, resources, astronomical and military satellites.

"The space program is way down at the botton of the totem poll already" with regard to the nation's priorities, Gurney said. He said Americans spend 43 cents out of every tax dollar on social and welfare programs and only one and one-half cents on the space program. "One-third of one cent will be all that we are going to spend for the space shuttle," Gurney said.

He criticized the space shuttle cost estimates used by the critics for "including ongoing costs and payload costs with what the shuttle is going to cost through the research and development stage." Gurney said that there would be additional payload costs whether the space shuttle or another type of booster launched a satellite.

Rep. Louis Frey Jr. (R Fla.) is a member of the House Science and Astronautics Committee and its Manned Space Flight Subcommittee.

"We have to go from an experimental to an operational use of space," Frey said in an interview Jan. 26. "There is a continuing need to keep man in space."

"There are many things that a man can do in space better than machines," Frey said.

Frey said that the shuttle can be justified because it will "replace many launch vehicles" and make "payloads less expensive."

He rejected the priorities argument advanced by critics of the shuttle. He stated that the proposed space shuttle program was modest enough to fit in with other national priorities.

Sen. Walter F. Mondale (D Minn.), in an interview Jan. 28, said that he was not anti-space, but

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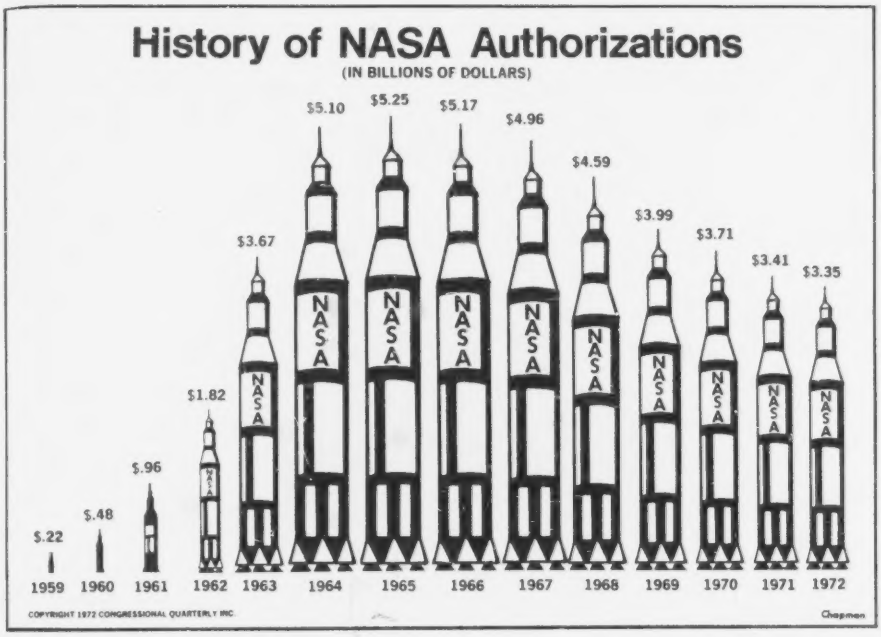

that he opposed the shuttle because it was a waste. He added that he supported the Apollo program.

Congress supported the effort to land men on the moon because it involved a "crisis of prestige" and it was important to "recoup our posture as the pre-eminent technological society in the world," Mondale said.

He said he did not believe that the shuttle could be justified as useful or of scientific value.

Mondale characterized the shuttle as "a manned extravaganza to get public support." He said that the money should "go for priorities at home."

He added, "It should go to solve human problems such as mass transit, housing, education and the environment."

Rep. Edward I. Koch (D N.Y.) opposed the shuttle as a member of the House Science and Astronautics Committee during the 91st Congress. He now serves on the Banking and Currency Committee.

Koch said in an interview Jan. 26 that his opposition was based on priorities. He added, "Until we have mass transit to LaGuardia and Kennedy (Airports), I'm not interested in the space shuttle."

Koch said that $600-million was spent on mass transit in fiscal 1972 and one-third that amount or $200-million has been requested for the space shuttle in fiscal 1973. He characterized this as an outrage. Koch added, "How many people can you get in a space shuttle anyway?"

He said that he was not opposed to space exploration but felt that getting rats out of slum apartments, dealing with heroin addiction and building housing was more important than the space shuttle.

NASA Reaction

Fletcher said some critics of the space shuttle were "deliberately confusing the facts." He added, "Our best estimate is that it will cost $5.5-billion for research and development of the shuttle. Another $1-billion, a 20-percent increase allowance, has been added to take care of unforeseen research and development problems."

"The shuttle will more than pay for itself with 40 flights per year," Fletcher said. This figure included civilian satellite launchings by NASA and military launchings of Defense Department satellites.

"I am completely convinced that the shuttle is the right thing to do. If I wasn't, I wouldn't have gone ahead with it," he added.

"It is a big program; $5.5-billion is a lot of money, and as a taxpayer, I think questions ought to be asked. I just don't like the distortion of the data," Fletcher said.

Fletcher said opponents of the space shuttle "exaggerated the real research and development costs of the shuttle" and "added in satellite costs with shuttle costs." He continued, "These satellites would be launched with or without the shuttle."

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A BIBLIOGRAPHY ON THE 1984-1985 NATIONAL COLLEGE DEBATE TOPIC

by
B. F. Mangan
Senior Bibliographer, Science
Library Services Division

and
Marcia Smith
Specialist in Aerospace and Telecommunications Systems
Science Policy Research Division

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INTRODUCTION

This bibliography is designed to help college debaters with research on the 1984-1985 Intercollegiate Debate Topic: "Resolved: that the U.S. Federal Government should significantly increase the exploration and/or development of space beyond the Earth's mesosphere."

The selected items have been arranged in five sections: history and overview; space law; space exploration and development, including space policy and economic aspects, technology, industrialization, space station, living in space, planetary exploration, and foreign space programs; militarization of space; and resource allocation among competing national priorities. By agreement with the Project Coordinator for the Committee on Intercollegiate Debate and Discussion of the Speech Convention of America, this document does not take into account questions of specific alternative uses of the current or proposed Federal funds devoted to U.S. space programs, and the effect that such alternatives might have upon the scope, direction, or viability of the U.S. space program.

This annotated bibliography is composed of selected periodical articles and books. The majority of the citations were obtained from the computerized Congressional Research Service Bibliographic Data Base, created and maintained by the Library Services Division. Other material was selected from collections within the Congressional Research Service and elsewhere in the Library of Congress.

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----- Who owns the Moon? Foreign Service journal, v. 58, July-Aug. 1981: 22-25.

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Smith, Delbert D. The Moon Treaty and private enterprise. Astronautics & aeronautics, v. 18, Jan. 1980: 62-65.

Advocates that the U.S. should protect its interests by clarifying "use" and "exploitation" in the U.N.'s proposed Moon Treaty.

Symposium: the new era in outer space. Akron law review, v. 13, spring 1980: 593-697.
Contents.--The new era in outer space, by H. DeSaussure.--Private management and operation of the Space Shuttle: some legal problems related to market entry, by G. Robinson.--Some aspects of third party liability in Space Shuttle operations, by T. Wolcott.--Current status of NASA Space Shuttle regulations, by G. Sloup.--STS-legal connotations, by M. Menter.--International law and military activities in outer space, by R. Bridge.--Military use of the Space Shuttle, by W. Reed and R. Norris.--The operator's liability with regard to transport of goods by Space Shuttle, by I. Diederiks-Verschoor.

United Nations. Office of Public Information. The United Nations and outer space. New York, United Nations, 1977. 40 p.
"United Nations publication. Sales no. E.77.1.9"
This booklet briefly summarizes some of the main areas of interest to the United Nations concerning outer space."

U.S. Congress. House. Committee on Foreign Affairs. The second U.N. Conference on the Peaceful Uses of Outer Space (Unispace 1982) August 9-12, 1982; report. Washington, G.P.O., 1983. 27 p.
At head of title: 97th Congress, 2nd session. Committee print.

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. Unispace '82. Report and hearing, 97th Congress, 2nd session. July 14, 1982. Washington, G.P.O., 1983. 742 p.
"No. 160"

U.S. Congress. Senate. Committee on Aeronautical and Space Sciences. Space law: selected basic documents; staff report. Washington, G.P.O., 1976. 464 p.
At head of title: 94th Congress, 2nd session. Committee print.

U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Space law: selected basic documents, second edition. Washington, G.P.O., 1978. 600 p.
At head of title: 95th Congress, 2nd session. Committee print.

Wiewiorowska, Krystyna. Some problems of state responsibility in outer space law. Journal of space law, v. 7, spring 1979: 23-38.
Examines the problems relating to state responsibility for space activities undertaken by the state, its citizens or in cooperation with other states.

Williams, Maureen. The geostationary orbit: a limited natural resource from outer space. International relations, v. 6, Nov. 1979: 662-671.
Reviews agreements and conferences covering the placement of communications satellites in a geostationary orbit. The geostationary orbit has been declared a limited natural resource from outer space by the U.N. Working Group on Direct Broadcasting Satellites.

----- International law in the pursuance of sun power as a new source of energy. International relations, v. 5, May 1977: 24-39.
Discusses the application of international and space law to the utilization of solar energy on earth.

III. SPACE EXPLORATION AND DEVELOPMENT: SCIENTIFIC AND COMMERCIAL

A. Policy and Economics

Chadwick, Susan. New visions, failed dreams: what's our payoff from NASA lift-offs? Houston City magazine, v. 8, Apr. 1984: 105-107, 124, 126-128, 131-133.
Looks at probable economic benefits that the Johnson Space Center may have for the Houston area.

Colombo, Giuseppe. Space technology: where will fiction meet reality? Technology review, v. 84, Oct. 1981: 69-77.
"The fact that we have not yet undertaken many technically feasible projects to bring the resources of space to bear on our urgent needs on earth suggests that the line between reality and fiction depends not on science but on social and political factors."

Cowen, Robert C. Space: where next for the US? Christian Science monitor, Dec. 27, 1983: 16-17; Dec. 28: 14-15; Dec. 29: 14.
Contents.--NASA-ripe for a renaissance.--A new agenda for NASA beyond the pioneering stage.--Building a permanent presence in orbit--a laboratory/service station/facility.

Etzioni, Amitai. The Moon-doggle: domestic and international implications of the space race. New York, Doubleday & Company, inc., 1964. 198 p.
The author contends "that the space program in general--especially the moon project and particularly the landing of a man there--has claimed an undue amount of attention and resources; that the race into space has some dangerous side-effects that threaten the vitality of our science, undermine our security, and retard rather than advance our economy."

Evans, Michael K. The economic impact of NASA R&D spending. Prepared for the U.S. National Aeronautics and Space Administration. Bala Cynwyd, Pa., Chase Econometric Associates, 1976. 121 l.
"NASA-CR-144352"
"This study found that an increase in NASA R & D spending increases the rate of technological change and reduces the rate of inflation for two reasons. First, in the short run it redistributes demand in the direction of the high-technology industries, thus improving aggregate productivity in the economy. As a result, NASA R & D spending tends to be more stabilizing than general government spending during a period of recovery. Second, in the long run, increased NASA R & D spending expands the production possibility frontier of the economy by increasing the rate of technological progress."

Farrell-Gisse, Katrina, and Hoyt Gimlin. American options in space. Washington, Congressional Quarterly, 1983. 131-148 p. (Editorial research reports, 1983, v. 1, no. 7)

Gwynne, Peter. Shuttle woes raise doubts of cost-effective turnaround. Industrial research & development, v. 24, Jan. 1982: 68-70, 72.
Questions the economic viability of the Space Shuttle.

Hertzfeld, Henry R. Measuring NASA's impact on the economy. Unpublished paper. 1981. 18 p.
To be part of House document noted on p. CRS-v of this bibliography.
Paper presented at Annual Meeting of the Technology Transfer Society, Washington, D.C., June 16, 1981 by Henry R. Hertzfeld, Senior Economist, National Aeronautics and Space Administration.
Contends that "the space program has had beneficial returns to the economy in excess of the money spent on it."

Hussey, W. John. The economic benefits of operational environment satellites. Washington, National Environmental Satellite, Data, and Information Service, U.S. National Oceanic and Atmospheric Administration, 1983. 40 p.
Identifies and attempts to quantify benefits derived from the United States Operational Environmental Satellite System. Demonstrates how environmental satellites have helped to save lives and property from natural disasters and improved the efficiency of certain sectors of the national economy.

International cooperation in space: how to enhance the results, share the risk. Government executive, v. 16, Mar. 1984: 9, 12, 14.
Sees benefits in international cooperation in space because overseas funding and commitments provide program stability "against 'raids' on the U.S. portion of the commitment by politicians and others who would like to see the budget dollar spent elsewhere from time to time."

Keaton, Paul W. Why billions can and should be spent on space. Astronautics & aeronautics, v. 21, May 1983: 86-88, 90-92.
Contends that "over the next twenty-two years GNP will total about $100 trillion, easily supporting $130 billion for large focused space programs."

Kennan, Erlend A., and Edmund H. Harvey, Jr. Mission to the moon: a critical examination of NASA and the space program. New York, William Morrow & Co., 1969. 396 p.
"This book is harshly critical of America's space program. It is an indictment of irresponsibility at many levels, not only within the National Aeronautics and Space Administration, America's civilian space agency, but in the relationships of NASA with the Congress, the Defense Department, the aerospace industry, the scientific community, and the press." Contains a detailed study of the Apollo 204 accident of January 27, 1967 that resulted in the deaths of three astronauts Virgil Grisson, Edward White, and Roger Chaffe.

Logsdon, John M. U.S.-European cooperation in space science: a 25-year perspective. Science, v. 223, Jan. 6, 1984: 11-16.
Foresees "continued productive cooperation between the United States and Europe in space science" even though a competitive dimension has been added due to the increased level of space capability which European nations have developed.

Marsh, Peter. Scientists gain a foothold in space. New scientist, v. 99, Sept. 22, 1983: 874-879.
Notes that the scientific community is divided over the probable benefits of Spacelab.

Marth, Del. Have rocket, will rent. Nation's business, v. 71, Aug. 1983: 32-35.
"American rockets that can be used only once, like the Titan, were to be phased out of the space program but may get a reprieve because of their potential for carrying commercial payloads."

Miller, Jon D. Is there public support for space exploration? Environment, v. 26, June 1984: 2-35.
Contends that there is a strong core of support for NASA's space programs.

Moeser, John V. The space program and the urban problem: case studies of the components of national consensus. Washington, Program of Policy Studies in Science and Technology, George Washington University, 1969. 44 p; (George Washington University, Washington, D.C. Program of Policy Studies in Science and Technology. Staff discussion paper 404)

"By analyzing why the American efforts in space were sustained by a strong, cohesive, and long-lasting consensus and why the question of urban poverty fails to generate a comparable consensus, this paper suggests certain variables that seem to be essential prerequisites for any viable national consensus."

Quantifying the benefits to the national economy from secondary applications of NASA technology. Prepared by Mathematica, Inc. for the U.S. National Aeronautics and Space Administration. Princeton, N.J., Mathematica, 1976. 2 v.

"NASA-CR-2674"

The first volume is a 10 page executive summary.

"The purpose of this study is to develop preliminary estimates of the economic benefits to the U.S. from secondary applications of NASA technology. If technology is defined as the body of knowledge concerning how society's resources can be combined to yield economic goods and services, then NASA technology represents NASA's contribution to this body of technical knowledge. Secondary applications refer to uses of NASA-generated knowledge for purposes other than those primary mission-oriented ones for which the original R & D was done. These applications occur whenever a non-NASA entity, with or without encouragement from NASA, uses this knowledge in some economic activity."

Rosenberg, Tina. Mission out of control. New republic, v. 190, May 14, 1984: 18-21.

Criticizes NASA's emphasis on manned missions. Contends that the technological innovations space has given us have come from unmanned programs. Warns that "the key to economically viable space manufacturing is doing the job more cheaply than on Earth. That means robotics."

Sagan, Carl, James Beggs, and George Keyworth. Dumping space. New York, WNET/Thirteen, 1981. 7 p.

The MacNeil/Lehrer Report, Nov. 4, 1981.

James Beggs, NASA Administrator, George Keyworth, Presidential Science Advisor, and Dr. Carl Sagan discuss the future of U.S. space programs.

Schefter, Jim. It's time to stop the space retreat. Popular science, v. 221, Oct. 1982: 32, 34, 38, 40-43, 45.

Claims that the "U.S. space program in the 1980's is an ambiguous hodgepodge of brilliant events, great potential, unkept promises, and downcast vision." Points to the economic, technological, and defense benefits of a comprehensive space program.

Smith, Marcia S. 1983 space activities and a look forward at 1984. Congressional Research Service review, v. 5, Mar. 1984: 2-4, 20-21.

Reports on space launches during 1983 and predicts space activities for the U.S., U.S.S.R., the European Space Agency, China, India and Japan.

Space Shuttle. Prepared by Lyndon B. Johnson Space Center. Washington, Scientific and Technical Information Office, National Aeronautics and Space Administration, for sale by the Supt. of Docs., G.P.O., 1976. 89 p.

"NASA-SP-407"

Describes the Space Shuttle vehicle in detail and emphasizes the economic and social benefits of the Space Transportation System.

Tarter, Donald E. The Space Shuttle: prologue or postscript? World Future Society bulletin, v. 15, July-Aug. 1981: 1-6.
Fears that public apathy may set in after the initial success of the space shuttle and the consequence of this will be to close off human movement into outer space.

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. United States civilian space policy. Hearings, 96th Congress, 2nd session. July 23-24, 1980. Washington, G.P.O., 1980. 246 p.
"No. 153"

U.S. Congress. Office of Technology Assessment. Civilian space policy and applications. [Washington, For sale by the Supt. of Docs., G.P.O., 1982] 391 p.
"OTA-STI-177, June 1982"

----- Space science research in the United States: a technical memorandum. [Washington, For sale by the Supt. of Docs., G.P.O.] 1982. 50 p.
Contends that "despite its many noteworthy achievements over the past 20 years, the space science program of the United States, has, as a whole, been placed in a holding pattern, and, in significant parts, been forced to retrench. Many now see space science as in a state of crisis. The National Aeronautics and Space Administration's (NASA's) overall budget for space science has, in general, been on the decline since 1974, and that of one category, planetary science, has declined precipitously."

U.S. Congress. Senate. Committee on Appropriations. Department of Housing and Urban Development, space, science veterans, and certain other independent agencies appropriations for fiscal year 1974. Hearings, 93rd Congress, 1st session. Washington, G.P.O., 1973. 908 p.
Part 1--National Aeronautics and Space Administration, Veterans' Administration.
In testimony Dr. Brian O'Leary a former NASA scientist criticizes the cost of the space shuttle program and is unconvinced of its economic justification. O'Leary expresses concern over NASA priorities and contends that the space transportation systems has "become the end rather than the means of space exploration."
Dr. James A. Van Allen, professor of physics and head of the Department of Physics and Astronomy at the University of Iowa notes that the "unmanned/automated/commandable spacecraft has provided at least 80 percent of the new scientific results and almost all the utilitarian applications of space technology."
Dr. George W. Rathgens from the Massachusetts Institute of Technology contends that the space shuttle should have low priority compared with other space programs and compared with other national needs.

U.S. General Accounting Office. Issues concerning the future operation of the Space Transportation System; study. [Washington] 1982. 26 p.
"GAO/MASAD-83-6, Dec. 28, 1982"
"The first priority of the Space Transportation System program now is to make the system fully operational and cost effective in providing routine access to space. This study addresses some of the major operational issues facing the National Aeronautics and Space Administration and the budgetary issues facing the Congress as this new era in space operations begins."

----- NASA report may overstate the economic benefits of research and development spending. Report of the Comptroller General of the United States. Washington, G.A.O., 1977. 53 p.
"PAD-78-18, Oct. 18, 1977"
GAO conducted an independent assessment of the NASA-commissioned report entitled "The Economic Impact of NASA R & D Spending," by Chase Econometrics, Inc. and concluded that the "Chase study does not prove convincingly that the benefits are as large as stated."

U.S. Office of Aeronautics and Space Technology. NASA space systems technology model. Washington, National Aeronautics and Space Administration, Office of Aeronautics and Space Technology, 1980. 3 v.
Contents.--Vol. 1: System/program descriptions and technology needs. --Vol. 2: Space technology trends and forecasts.--Vol. 3: Opportunity system/programs and technologies.

United States civilian space programs, 1958-1978; report prepared for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives, 97th Congress, 1st session, by the Science Policy Research Division, Congressional Research Service, Library of Congress. Vol. 1. Washington, G.P.O., 1981. 1339 p.
"Serial D"
At head of title: Committee print.
Presents information on NASA and its relationship to U.S. space policy. Describes U.S. launch vehicles, manned space flight, the Space Transportation System, space sciences, and materials processing in space.

United States civilian space programs: volume II--applications satellites; report prepared for the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives, 98th Congress, 1st session, by the Science Policy Research Division, Congressional Research Service, Library of Congress. Washington, G.P.O., 1983. 381 p.
At head of title: Committee print.
"Serial--M"

Van, Jon. The marvelous machines we send into space. Chicago tribune magazine, Oct. 18, 1981: 44-45, 47, 52, 54.
Warns that costs may hinder further breakthroughs in space exploration.

B. Technology

Denver Research Institute. Space benefits: the secondary application of aerospace technology in other sectors of the economy. [Washington, National Aeronautics and Space Administration, 1981] 1 v. (various pagings)
Points to the economic benefits of the transfer of aerospace technology to other sectors of the U.S. economy. Summarizes "585 examples of beneficial use for NASA technology by public and private organizations."

Fitzgerald, Paul E., Jr., and Edward A. Gabris. The Space Shuttle focused-technology program: lessons learned. Astronautics & aeronautics, v. 21, Feb. 1983: 60-67, 72.
Technologies developed for the Space Shuttle will be incorporated in the space station.

Geostationary platform systems concept definition study. Vol. 1: Executive summary. Prepared by General Dynamics/Convair in cooperation with Communications Satellite Corp. Washington, U.S. National Aeronautics and Space Administration [available from NTIS] 1980. 72 p.
"NASA-CR-16147"
Concludes that geostationary platforms offer significant cost savings compared to individual satellites.

Kolm, Henry. An electromagnetic "slingshot" for space propulsion. Technology review, v. 79, June 1977: 60-66.
"Harnessed sunlight could produce electricity to drive powerful electromagnetic systems to launch ore from the moon and to propel asteroids and space stations."

Liquid-rocket propulsion technology. Astronautics & aeronautics, v. 21, Apr. 1983: 46-52, 54-56.
Contends that "the federal government should reinstate and firmly commit a long-range integrated program to develop liquid-rocket technology for the coming generation of space systems."

Spinoffs from the space program. Business week, no. 2606, Oct. 8, 1979: 26G-26H, 26K-26L, 26S.
Contents.--Next steps for mankind--the challenge of space, by A. Stevenson.--Spinoffs for solar energy, by P. Glaser.--The energy analysis program, by W. Marshall.--Technology transfer, by Z. Lansky.--The automated management information system, by G. Monroe and F. Helfand.--Insulation technology was ready for the space age, by C. Sulewski.--One giant leap of the industrial kind, by J. Adams.

U.S. Congress. House. Select Committee on Aging. Applications of space technology for the elderly and handicapped. Joint hearings, 96th Congress, 1st session. July 19-20, 1979. Washington, G.P.O., 1979. 168 p.
"Pub. no. 96-191"
"No. 38"

U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Subcommittee on Science, Technology, and Space. Symposium on the future of space science and space applications. Hearing, 95th Congress, 2nd session. Feb. 7, 1978. Washington, G.P.O., 1978. 109 p.
"Serial no. 95-58"

U.S. National Aeronautics and Space Administration. Spinoff 19--: an annual report. Washington, For sale by the G.P.O., 1974-
Volumes in this monographic series dated prior to 1974 were distributed by NTIS. Spinoff and the title Technology utilization program report are both used.
Describes technology developed through aerospace research and illustrates how NASA seeks to stimulate technology utilization to enhance productivity and quality of life.

----- Technology for large space systems: a special bibliography with indexes. Washington [Available from NTIS] 1981. 1 v. (various pagings)
"NASA SP-7046(05)"
Presents an annotated bibliography of documents "that define specific missions that will require large space structures to achieve their objectives. The methods of integrating advanced technology into system configurations and ascertaining the resulting capabilities is also addressed."

Ziska, Patrick J. Space: putting spinoffs to work. AFL-CIO American federationist, v. 85, Nov. 1978: 15-19.
Describes how space developed technology has been transferred to medicine, transportation, public safety, energy and pollution remedies, construction, communications, industrial and agricultural processes, sports, and recreation.

C. Industrialization

Baker, David. Cargo spaceships after Shuttle. Flight international, v. 115, Mar. 17, 1979: 836-838.
"Over the next few years the first reusable launcher, the Space Shuttle, will make it easier and cheaper to place payloads in orbit. Author looks at the Shuttle derivatives and new launchers that will be required when man begins building larger structures in space."

Baum, Rudy M. Firms eye growing role, with NASA, in commercializing space. Chemical & engineering news, v. 61, Oct. 17, 1983: 20-21, 27, 29.
Illustrates how businesses ranging from large aerospace firms to small entrepreneurs are becoming involved in the commercial uses of space.

Bittence, John C. Materials engineering in the sky. Materials engineering, v. 92, Oct. 1980: 34-41.
Describes the benefits of processing materials in outer space.

Bulloch, Chris. Materials processing in space: plenty of prophets, but what about profits? Interavia, v. 39, July 1984: 679-683.
Space offers envrionmental conditions, such as a high degree of vacuum and microgravity, that make processing of materials in space attractive, but there are economic risks involved.

Businesses grab piece of space. High technology, v. 1, Sept.-Oct. 1981: 14-18.
Describes the economic benefits of a reusable Space Shuttle. Payloads include communication satellites, a space telescope and an Automated Beam Builder to develop large structures in space.

Bylinsky, Gene. Space will be the next big construction site. Fortune, v. 99, Feb. 26, 1979: 63-65, 68.
Describes the plans, dreams, and problems associated with building large structures in space for communications and solar energy generation.

Commercialization of land and weather satellites; report prepared by Science Policy Research Division, Congressional Research Service, for the Subcommittee on Space Science and Applications and the Subcommittee on Natural resources, Agriculture Research and Environment, transmitted to the Committee on Science and Technology, U.S. House of Representatives, 98th Congress, 1st session. Washington, G.P.O., 1983. 365 p.
At head of title: Committee print.
"Serial H"

Commercialization of space. Aviation week & space technology, v. 120, June 25, 1984: 40-201.
This collection of articles covers such topics as economic policies to stimulate space commercialization, processing of materials and drugs in space, Landsat commericalization, and the viability of commercial space ventures.

Covington, Clarke, and Robert O. Piland. Space Operations Center: next goal for manned space flight? Astronautics and aeronautics, v. 18, Sept. 1980: 30-37.
Presents the concept of the space operations center, a permanent, manned facility in low Earth orbit, the mission of which would be the construction, assembly, and servicing of space systems and spacecraft.

Criswell, David, and Peter Marsh. Working on the Moon. New scientist, v. 92, Oct. 1, 1981: 30-33.
Sees the Moon as a natural site for factories and for mining materials.

Deudney, Daniel. Coming down to Earth: industry in space is a mirage of abundance. Across the Board, v. 19, Nov. 1982: 41-45.
"Although space manufacturing may become a modest industry some day, large-scale space industrialization is an unworkable attempt to escape from the problems of earth."

Dooling, Dave. The first space factories. Space world, v. S-3-219, Mar. 1982: 4-7, 32-33.
Reports on how future Space Shuttle missions will test the possibility of materials processing in low gravity.

----- Space factories in 1997. Spaceflight, v. 19, Oct. 10, 1977: 342-347; Oct. 25: 390-392.
Outlines results to date of materials processing experiments conducted in space under the near-vacuum conditions of microgravity. Describes the transportation vehicles and orbiting facilities envisioned for space processing applications in such areas as pharmaceuticals, ceramics, and electronics. Discusses the role industry might play in developing these applications.

For industry it's almost lift-off time. Business week, no. 2795, June 20, 1983: 62-65.
"A recent NASA-funded survey turned up 84 companies interested in doing some 244 experimental and commercial projects in orbit."

Gaffey, Michael J., and Thomas B. McCord. Mining outer space. Technology review, v. 79, June 1977: 50-59.
"Asteroids contain many of the minerals in short supply on earth. Detecting and recovering these minerals could be technically feasible and financially rewarding."

Grey, Jerry. Implications of the Shuttle: our business in space. Technology review, v. 84, Oct. 1981: 34-42, 44, 46.
Explores the commercial possibilities of the Space Shuttle. Calls for "imaginative public-private partnerships" to assure commercial success.

Hartmann, William K. Mines in the sky promise riches, a greener Earth. Smithsonian, v. 13, Sept. 1982: 71-76.
Foresees the mining of asteroids for metals needed on Earth.

Hosenball, S. Neil. The Space Shuttle in perspective. Journal of space law, v. 9, spring-fall 1981: 69-75.
Projects that "insurance to reduce the risk, incentives that NASA is willing to make available to U.S. industry, and the demonstrated willingness of industry and the financial community to invest their funds in space ventures make it clear . . . that the new Shuttle capabilities will exponentially increase commercial activities in space during the decade of the eighties."

Humphlett, Patricia E. Proposed sale of Landsat and the weather satellites. Congressional Research Service review, v. 4, Oct. 1983: 12-14.
"According to the Administration, the private sector is better equipped than the government to expand the Landsat data market; the private sector has the profit incentive and experience in marketing new products."

Kinnucan, Paul. Space business. High technology, v. 3, Oct. 1983: 42-45, 48-51.
Warns that a fear of high risks and budget cutbacks could impede commercialization of space.

Lepkowski, Wil. U.S. space policy ready for next big leap. Chemical & engineering news, v. 62, Feb. 1984: 9-16.
Looks at future commercialization of space technology including satellites, research and development in space and the future military uses of space by the U.S.

Lockerby, Robert W. Space-based manufacture. Monticello, Ill., Vance Bibliographies, 1984. 14 p. (Public administration series: biibliography P-1473)

Logsdon, John M. Space commercialization: how soon the payoffs? Futures, v. 16, Feb. 1984: 71-78.
Concludes "that commercialization is the wrong theme to be stressing now as the major justification for future space activities. Governments should take the actions required to remove barriers to private sector investment in space, but should also recognize that such actions are unlikely to lead to a flood of private investments."

McLearn, Donald C. Why drugs will be made in space. FDA consumer, v. 17, Nov. 1983: 19-23.
Describes the manufacturing technique called continuous flow electrophoresis which separates materials in solution by subjecting them to an electrical field and how this process, when used in space, can produce great quantities of materials such as enzymes, hormones and proteins for use in drugs.

O'Neill, Gerard K., Gerald Driggers, and Brian O'Leary. New routes to manufacturing in space. Astronautics & aeronautics, v. 18, Oct. 1980: 46-51.
Contend that "because of energy costs it makes sense to use lunar materials for the construction of products needed in space. Less than a twentieth of the energy to bring a ton to orbit from the Earth will bring it there from the Moon."

Reagan, Ronald. Remarks to National Aeronautics and Space Administration employees at the Goddard Space Flight Center, August 30, 1984. Weekly compilation of Presidential documents, v. 20, Sept. 3, 1984: 1197-1200.
In this speech the President discusses the commercial opportunities of space.

Remote sensing and the private sector: issues for discussion. Washington, U.S. Office of Technology Assessment, for sale by the Supt. of Docs., G.P.O., 1984. 141 p.
"OTA-TM-ISC-20"
"This technical memorandum, which was requested by the House Science and Technology Committee and the House Government Operations Committee, is designed to help Congress determine the appropriate requirements and conditions for private sector ownership of the U.S. land remote-sensing system." Examines the difficulty of transferring Government developed technology to the private sector.

Smith, Marcia S. The next decade in space: increased international economic competition. Congressional Research Service review, v. 3, July-Aug. 1982: 2-4, 25.
"As the U.S. space shuttle enters operational status later this year, it will face stiff competition in providing launch services to commercial and foreign customers from the European Space Agency's Ariane launch vehicle. Two other space activities long dominated by the United States also will face competition during the 1980s: France plans to launch a remote sensing satellite in 1984 which will compete with the U.S. Landsat satellites (other countries have similar plans), and Japan has the lead in developing certain new communications satellite technologies."

Should we make products on the Moon? Astronautics & aeronautics, v. 21, June 1983: 80-85.
"By the turn of the century, just a good development cycle away, commercial needs for large amounts of certain materials in Earth orbit may justify producing them on the Moon."

Space industrialization. Prepared by Science Applications, Inc. Huntsville, Ala., SAI [available from NTIS] 1978. 4 v.
"NASA-CR-150752--NASA-CR-150755." Prepared under NASA contract.
Projects benefits that could accrue to the U.S. from the investment of public and private resources in space industrialization.
Contents.--Vol. 1: An overview.--Vol. 2: Opportunities, markets, and programs.--Volume 3: World and domestic implications.--Volume 4: Appendices.

United Nations. Secretariat. Bibliography of the literature on activities that might be carried out using space platforms. New York, United Nations, 1980. 11 p. (United Nations. Document A/AC.105/265)

U.S. Congress. House. Committee on Government Operations. Legislation and National Security Subcommittee. International implications of proposed sale of Landsat satellite. Hearing, 98th Congress, 1st session. Sept. 28, 1983. Washington, G.P.O., 1984. 147 p.

U.S. Congress. House. Committee on Science and Technology. Commercial Space Launch Act; report to accompany H.R. 3942 including cost estimate of the Congressional Budget Office. Washington, G.P.O., 1984. 24 p. (Report, House, 98th Congress, 2nd session, no. 98-816)

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Natural Resources, Agriculture Research and Environment. The commercialization of meteorological and land remote-sensing satellites. Hearings before the Subcommittee on Natural Resources, Agriculture Research and Environment and the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives, 98th Congress, 1st session. Washington, G.P.O., 1984. 1550 p.
"No. 53"
Hearings held Apr. 14-Nov. 9, 1983.

----- Land Remote-Sensing Commercialization Act of 1984--H.R. 4836 and H.R. 5155. Hearing before the Subcommittee on Natural Resources, Agriculture Research and Environment and the Subcommittee on Space Science and Applications of the Committee on Science and Technology, U.S. House of Representatives, 98th Congress, 2nd session. Mar. 6, 1984. Washington, G.P.O., 1984. 165 p.

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. H.R. 7412: the Space Industrialization Act of 1980. Hearings, 96th Congress, 2nd session. June 11, 12, 1980. Washington, G.P.O., 1980. 88 p.
"No. 132"

----- Review of materials processing in space, 1983. Hearings, 98th Congress, 1st session. Sept. 14 and 15, 1983. Washington, G.P.O., 1984. 130 p.
"No. 42"

----- Space commercialization. Hearings, 98th Congress, 1st session. Washington, G.P.O., 1983. 385 p.
"No. 23"
Hearings held May 3-18, 1983.

----- Space industrialization. Hearing, 95th Congress, 1st session. Sept. 29, 1977. Washington, G.P.O., 1977. 204 p.
"No. 26"

----- The Space Industrialization Act of 1979. Hearings, 96th Congress, 1st session, on H.R. 2337. Washington, G.P.O., 1979. 288 p.
"No. 47"
Hearings held May 22-23; June 26-27, 1979.

U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Policy and legal issues involved in the commercialization of space; printed at the direction of Hon. Bob Packwood, Chairman. Washington, G.P.O., 1983. 52 p. (Print, Senate, 98th Congress, 1st session, committee print, S. Prt. 98-102)

U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Subcommittee on Science, Technology, and Space. Landsat commercialization. Hearing, 98th Congress, 2nd session, on S. 1855, S. 1861 and S. 2292. Mar. 22, 1984. Washington, G.P.O., 1984. 137 p. (Hearing, Senate, 98th Congress, 2nd session, S. Hrg. 98-747)
"Serial no. 98-69"

U.S. General Accounting Office. Effects on users of commercializing Landsat and the weather satellites; report by the Comptroller General of the United States. Feb. 24, 1984. Washington, G.A.O., 1984. 53 p.
"GAO/RCED-84-93"
"In March 1983, the administration proposed to transfer the National Oceanic and Atmospheric Administration's satellites--a land-observing satellite, called Landsat, and the weather satellites--to the private sector. This report discusses how these satellites are used worldwide and how their commercial operation might affect users."

VonPuttkamer, Jesco. The industrialization of space. Futurist, v. 13, June 1979: 192-199, 201.
"In the next few decades, commercial ventures in space could provide improved information services, unique space-derived products, and perhaps up to 20% of America's electrical energy. In the long run, the commercialization of space could also act as a stepping-stone to the large-scale colonization of space."

----- The next 25 years: industrialization of space: rationale for planning. Washington, U.S. National Aeronautics and Space Administration, 1976. 29 p.
"NASA-TM-79360"
Presented at Southeast 2001: The Next 25 Years, World Future Society Conference, Atlanta, November 12-13, 1976.
Foresees NASA's space industrialization program contributing to increased productivity on Earth, and providing new growth options for the future which would include permanent settlement of space and long range colonization and exploration.

Wilford, John Noble. NASA's next mission: big business in space. New York times magazine, Sept. 18, 1983: 47, 50, 83-84, 86-88, 90.
"As it celebrates its 25th year, the agency is under pressure to shift its emphasis away from exploration and toward commercial and military uses of outer space."

D. Space Station

Begley, Sharon. The next step into space. Newsweek, v. 103, Feb. 6, 1984: 83.
Points out that the proposed $81 billion space station may siphon off funds from other research projects, and that in order to give the space station enough to do other projects will be designed around it and will not fly until the space station is built.

Covault, Craig. NASA to shift focus with space station. Aviation week & space technology, v. 120, Mar. 14, 1983: 99-101.
Contends that the decision to develop a permanently manned space station "will change the character of the National Aeronautics and Space Administration from an agency that is geared to support highly structured, brief forays into space into a more broadly based space operations team capable of supporting multiple long-term manned space flight activities."

----- President orders start on space station. Aviation week & space technology, v. 120, Jan. 30, 1984: 16-19.
"The space station goal . . . is designed to maintain the development capabilities of the space shuttle and provide a focal point for a generation of new U.S. commercial enterprise."

----- Space station pivotal in NASA future. Aviation week & space technology, v. 118, Mar. 14, 1983: 83-85, 87, 89.
"National Aeronautics and Space Administration space station studies have matured to a point where findings and decisions made over the next eight months could affect the character of the agency for the next 10-20 years. NASA managers forecast station development would substantially change the character of U.S. space operations and the structure of NASA itself."

Culbertson, Philip E. Current NASA space station planning. Astronautics & aeronautics, v. 20, Sept. 1982: 36-43, 59.
"It embraces requirements from the science, commercial, international, and national security user communities--the goal being a versatile operational base providing a permanent presence in space."

Dooling, Dave. Starting a space station for the right reasons. Astronautics & aeronautics, v. 20, July-Aug. 1982: 14, 16, 18, 20.
A space station will become a reality only after there is a commitment to the development of projects that will require the use of such a station.

Grey, Jerry. Moving from dream to reality. Environment, v. 25, Nov. 1983: 7-13, 33-40.
"The development of the next generation of space stations, our beachheads in space, is inevitable, not so much for the purpose of political ascendancy that motivated Appollo but for sound economic, security, scientific, and sociological reasons."

Krieger, James. Commercial projects for space station taking root. Chemical & engineering news, v. 61, May 2, 1983: 37-38.
The consulting firm of Booz-Allen & Hamilton is compiling a list of companies that may be potential users of the manned space station. NASA has awarded Booz-Allen a contract to continue user development for the commercialization aspects of a manned space station.

Olstad, Walter B. Targeting space station technologies. Astronautics & aeronautics, v. 21, Mar. 1983: 28-68.
Outlines the technology that would be necessary to design and operate a long-life space station.

Sharp, Peter W. Evolutionary concepts for a space station and the relevant utilisation potential. Journal of the British Interplanetary Society, v. 37, Apr. 1984: 157-162.
Describes the concepts for a U.S. manned space station and a European unmanned station.

[Space station] Aerospace America, v. 22, Sept. 1984: 47-50, 52, 54-64, 66, 68-72, 74-78, 80.
Contents.--Space station: the next logical step, by J. Beggs.--The Space station program plan, by J. Hodge.--Space station: technology development, by R. Carlisle.--Space station design: innovation and compromise, by L. Powell, A. Cohen, and M. Craig.--Space station: the world connection, by R. Freitag, R. Lottman, and L. Wigbels.

Space station: policy, planning, and utilization; proceedings of the AIAA/NASA Symposium on the Space Station, Arlington, Virginia, July 18-20, 1983. New York, AIAA, 1983. 216 p.
This symposium, held by the American Institute of Aeronautics and Astronautics and by NASA, explored the designs, technology and potential applications of an Earth-orbiting space station. The operational feasibility of a space station was also considered.

Waldrop, M. Mitchell. NASA wants a space station. Science, v. 217, Sept. 10, 1982: 1018-1021.
Describes proposals for a permanent U.S. space station in low earth orbit which range from a multi-billion dollar space city to a low-budget platform.

----- Space city. Science 83, v. 4, Oct. 1983: 60-67.
While NASA awaits approval to begin construction, its scientists plan a cost effective and utilitarian space station.

U.S. Congress. House. Committee on Science and Technology. Subcommittee on Space Science and Applications. NASA's space station activities. Hearing, 98th Congress, 1st session. Aug. 2, 1983. Washington, G.P.O., 1983. 158 p.
"No. 37"

U.S. Congress. Senate. Committee on Commerce, Science, and Transportation. Subcommittee on Science, Technology, and Space. Civil space station. Hearing, 98th Congress, 1st session. Nov. 15, 1983. Washington, G.P.O., 1984. 90 p. (Hearing, Senate, 98th Congress, 1st session, S. Hrg. 98-523)
"Serial no. 98-48"

Walklet, Donn C. Alternative strategies for space station financing. Prepared by Terra-Mar [company]. Washington, U.S. National Aeronautics and Space Administration. 1983. 33 p.
"NASA-CR-175412"
"The attributes of the proposed space station program are oriented toward research activities and technologies which generate long term benefits for mankind. Unless such technologies are deemed of national interest and thus are government funded, they must stand on their own in the market place. Therefore, the objectives of a United States space station should be based on commercial criteria; otherwise, such a project attracts no long term funding. There is encouraging evidence that some potential space station activities should generate revenues from shuttle related projects within the decade. Materials processing concepts as well as remote sensing indicate substantial potential. Furthermore, the economics and thus the commercial feasibility of such projects will be improved by the operating efficiencies available with an ongoing space station program."

E. Living in Space

The 1975 NASA/Stanford study of space colonization. Space world, v. N-1-157, Jan. 1977: 32-34.
"The final report of the 1975 NASA/Stanford University Summer Study in engineering systems design recommends that the United States adopt a program to move toward the colonization of space."

Ahn, Chung-Hae. NASA's biomedical research program. Washington, National Aeronautics and Space Administration [available from NTIS] 1981. 221 p.
"NASA SP-452"
Describes the various biomedical research programs of NASA which have been "established to investigate the major physiological and psychological problems encountered by man when he undertakes spaceflight."

Anderson, Michele, John A. Rummel, and Stanley Deutsch. Biospex: biological space experiments: a compendium of life sciences experiments carried on U.S. spacecraft. Washington, U.S. National Aeronautics and Space Administration, 1979. 297 p.
"NASA Technical Memorandum 58217"
Presents information on 27 years of life science experiments on U.S. spacecraft from sounding rocket flights carrying primates (1948) to the Apollo Soyuz mission (1975). Each experiment includes information on principal investigators, flight on which experiment was performed, specimens, results and conclusions.

The Apollo-Soyuz test project; medical report. Arnauld E. Nicogossian, ed. Washington, National Aeronautics and Space Administration [for sale by NTIS] 1977. 129 p.
"NASA SP-411"
"This report details the results of the clinical aspects as well as the preflight and postflight research studies that were performed on the astronauts."

Assessment of zero gravity effects on space worker health and safety. [Prepared by the] Lyndon B. Johnson Space Center. Washington [Available from NTIS] 1980. 119 p.
"DOE/ER-10025-T1"
"DOE/NASA Satellite Power System Concept Development and Evaluation Program."
"One objective of the study is to assess the effects of all currently known deviations from normal of medical, physiological and biochemical parameters which appear to be due to zero gravity (zero-g) environment and to acceleration and deceleration to be experienced, as outlined in the reference SPS design, by space workers."

Bell, Larry. Designing a village in space. Futurist, v. 15, Oct. 1981: 36-41, 44-46.
Reports on a space village--Spacehab--being designed by researchers at the University of Houston. Spacehab, a station for a hundred workers, would be ferried into orbit, in parts, by the Space Shuttle.

Chaikin, Andrew. Sick in space. Science 84, v. 5, June 1984: 51-55.
Examines the problem of motor sickness during space flight and research efforts by NASA directed toward understanding and controlling astronaus[illegible]

Compton, W. David. Living and working in space: a history of Skylab, by David W. Compton and Charles D. Benson. Washington, Scientific and Technical Information Branch, National Aeronautics and Space Administration, For Sale by the Supt. of Docs, G.P.O., 1983. 449 p. (The NASA history series, NASA SP 4208)

The origins and evolution of the Skylab project are traced. Some of the topics covered in this work are the Skylab program organization, congressional and budgetary matters concerning Skylab, astronaut training, the science projects conducted on Skylab and their results, and the spacecraft's reentry in July 1979.

Cooper, Henry S. F., Jr. Life in a space station. New Yorker, v. 52, Aug. 30, 1976: 34-44, 49-53, 55-57, 59-66; Sept. 6: 34-40, 44-53, 56-70.

Reports on the experiences of the three crews who manned Skylab, their mental and physical problems, the experiments they conducted, their relations with ground control, and over-all assessment of the project.

Ehricke, Krafft A. The extraterrestrial imperative. Air University review, v. 29, Jan.-Feb. 1978: 2-20.

Asserts that man will extraterritorialize, that is, live in more than one world. The early stages to accomplish this are space industrialization and providing energy to benefit earth. Later man will colonize space.

----- The extraterrestrial imperative; part two: productive earth orbits--new partnership through pressures and promise. Journal of the British Interplanetary Society, v. 32, Nov. 1979: 410-418.

Exoindustrialization is seen as a means of improving the quality of life on Earth.

Fowles, Jib. The improbability of space colonies. Space world, v. 0-6-174, June 1978: 10-15.

Summarizes the optimistic approach toward space colonies taken by O'Neill in his High frontier. Discusses the necessity for minute regimentation of populations in space and the question of space industry profitability. Concludes that the tremendous costs will preclude space colonization.

Haise, Fred W., Jr. Hardhats in space. Space world, v. Q-5-197, May 1980: 6-13.

Conceptualizes the conditions for "astroworkers", those who will construct platforms, factories and observatories in outer space.

Hopkins, Mark M. A preliminary cost benefit analysis of space colonization. Journal of the British Interplanetary Society, v. 30, Aug. 1977: 289-300.

"This paper presents the economic results of the NASA/Ames-Stanford ASEE 1975 Summer Study of Space Colonization, as modified by subsequent work. The participants at the Summer Study only attempted to design a technically feasible system. . . . This paper is written, as is the Summer Study, in a style suitable for the layman who is knowledgeable about the space sciences but not about economics. As a result, the analysis has been kept simple, several elementary economic concepts are explained, and much of the material of interest to economists has been placed in appendices."

Joyce, Christopher. Space travel is no joyride. Psychology today, v. 18, May 1984: 30-32, 34-37.

NASA will build a laboratory at the Johnson Space Center to study space sickness. Solving problems associated with space sickness such as lethargy, lack of appetite, cold sweats and nausea is important now that the U.S. is planning a permanent space station.

Lockerby, Robert W. Space colonies: the next frontier. Monticello, Ill., Vance Bibliographies, 1980. 7 p. (Architecture series: bibliography A-313)

Overbye, Dennis, and Natalie Angier. Man in space: special report. Discover, v. 5, Apr. 1984: 13-18, 20-21, 24-27, 30-31.
Contents.--In the armchair of the gods, by D. Overbye.--Next stop: Solar Max.--Welcome to the cosmic motel, by N. Angier.--The last frontier.

Parkinson, Bob, and D. J. Sheppard. Small high-technology communities on the Moon. Spaceflight, v. 19, Feb. 1977: 42-51.
Presents "two contrasting articles on the theme of the Lunar Colony. The first by Dr. R. C. Parkinson takes as its theme 'small high technology communities on the Moon', the second by Dr. D. J. Sheppard considers 'an alternative technology for the Lunar Colony'."

Paterson, Erik T. Space settlements--the medical perspective. Journal of the British Interplanetary Society, v. 34, Oct. 1981: 429-434.
"Following an examination of the physiological responses to weightlessness, the likely implications are considered from the point of view of many diseases. Cardiac, respiratory, neurological, musculoskeletal, renal, reproductive, digestive, psychiatric and infectious diseases are shown to be probably strongly influenced by low, or zero, gravity. Some implications for rehabilitation are also discussed. It is concluded that major health benefits may be realised from the migration into space."

Rowes, Barbara. Housewives in space. Omni, v. 4, June 1982: 64, 66-67, 128.
Research conducted by NASA between 1977 and 1981 on 27 volunteers demonstrated that women are both physically and emotionally capable of withstanding the rigors of space travel.

Russell, Allan Melvin. Human societies in interplanetary space: toward a fructification of the utopian tradition. Technological forecasting and social change, v. 12, Dec. 1978: 353-364.
Author outlines a vision of future space colonies that he describes as utopian in the positive sense. He describes the social and political ramifications he expects to accompany the expansion of the human realm into space.

Salkeld, Robert. Toward men permanently in space. Astronautics & aeronautics, v. 17, Oct. 1979: 60-69.
Argues for an international Earth-orbital habitat for research and technology.

Santy, Patricia. The journey out and in: psychiatry and space exploration. American journal of psychiatry, v. 140, May 1983: 519-527.
Reviews the U.S. and U.S.S.R. research in aerospace medicine that is relevant to psychiatry and suggests ways to expand psychiatry's clinical and research usefulness in future space exploration efforts.

Smith, Alexander G. Constraints limiting the rate of human expansion into the galaxy. Journal of the British Interplanetary Society, v. 34, Sept. 1981: 363-366.
Theorizes that "human expansion into a largely lifeless galaxy will be constrained by ecological and engineering factors."

Space colonization. Journal of the British Interplanetary Society, v. 30, Aug. 1977: whole issue.
Partial contents.--On the realisation of projects: with special reference to O'Neill space colonies and the like, by A. Cleaver.--A preliminary cost analysis of space colonization, by M. Hopkins.--Two new propulsion systems for use in space colonization, by T. Heppenheimer.--Radiation protection for space colonies, by E. Hannah.--Raw materials for space manufacturing--a comparison of terrestrial practice and lunar availability.

Space settlements; a design study. Richard D. Johnson, ed. Washington, National Aeronautics and Space Administration, for sale by the Supt. of Docs., G.P.O., 1977. 185 p.
"NASA SP-413"
"This report, like the design itself, is intended to be as technologically complete and sound as it could be made in ten weeks, but it is also meant for a readership beyond that of the aerospace community. Because the idea of colonizing space has awakened strong public interest, the report is written to be understood by the educated public and specialists in other fields."

F. Planetary Exploration

Berry, Richard, and Robert Burnham. Voyager 2 at Saturn. Astronomy, v. 9, Nov. 1981: 6-30.
As Voyager 2 continues on to Uranus scientists are left with years of data to analyze from its encounter with Saturn. The author describes the wealth of information that was obtained on the atmosphere, ring system, and moons of Saturn.

Dagani, Ron. The planets: chemistry in exotic places. Chemical & engineering news, v. 59, Aug. 10, 1981: 25-36.
"Two decades of planetary exploration have greatly increased scientists' understanding of the makeup of the solar system; few new planetary missions, however, will be initiated in the 1980's."

Jaffe, Leonard D., and Harry N. Norton. A prelude to interstellar flight. Astronautics & aeronautics, v. 18, Jan. 1980: 38-44.
Examines the scientific benefits and technology requirements of an interstellar precursor mission, i.e., a mission beyond the planets but not as far as the stars.

Karl, Van. The planets or bust. Astronomy, v. 10, May 1982: 9-17.
Reports on the NASA Solar System Exploration Committee's attempts to resurrect a class of low cost missions to revive the planetary exploration program.

Moore, Jesse W. Effective planetary exploration at low cost. Astronautics & aeronautics, v. 20, Oct. 1982: 28-38, 52.
Reports on the work of the Solar System Exploration Committee which has examined ways to reduce costs for planetary mission.

Morrison, David. A program for planetary exploration, by David Morrison and Noel W. Hinners. Science, v. 220, May 6, 1983: 561-567.
"On the basis of a two-year study, the NASA Solar System Exploration Committee recommends a core program of planetary missions through the year 2000. By incorporating a number of cost-saving measures, an exciting program of planetary exploration can be achieved within a highly constrained NASA budget."

----- Voyage to Jupiter, by David Morrison and Jane Samz. Washington, U.S. National Aeronautics and Space Administration [for sale by the Supt. of Docs., G.P.O.] 1980. 199 p.
"NASA SP-439"
Describe the planet Jupiter and its moons. Profile the voyager missions to Jupiter and Saturn. Highlight the wealth of information on the Jovian system that was relayed to Earth by the Voyager satellites.

----- Voyages to Saturn. Washington, U.S. National Aeronautics and Space Administration [for sale by the Supt. of Docs., G.P.O.] 1982. 227 p.
"NASA SP-451"
Partial contents.--The ringed planet.--Pioneer to Saturn.--The Voyager mission.--Encounter with Saturn.--The last picture show.

Neugebauer, Marcia. Mariner Mark II and the exploration of the solar system. Science, v. 219, Feb. 4, 1983: 443-449.
Discusses the costs, scientific objectives and mission requirements for the Mariner Mark II, a spacecraft concept for the next generation of deep-space missions.

Overbye, Dennis. Back to the planets. Discover, v. 4, May 1983: 29-33.
A plan based on standardized spacecraft is being developed by NASA to save planetary exploration from budgetary attrition.

Stoker, Carol, and Christopher P. McKay. Mission to Mars: the case for a settlement. Technology review, v. 86, Nov.-Dec. 1983: 27-30, 35-37.
See a permanent settlement on Mars as a focus for developing space. Note that Mars is the planet most hospitable and similar to Earth.

Wilson, Andrew. Exploration of the solar system: the 1980's and beyond. Space education, v. 1, July 1981: 13-17.
Lists future space projects that NASA envisions over the next decade. Budgetary constraints may limit many missions.

G. Foreign Programs

Clark, P. S. The Chinese space programme. Journal of the British Interplanetary Society, v. 37, 1984: 195-206.
Reviews the development of the Chinese rocket and space programs from the end of World War II to the present.

Covault, Craig. Soviets developing 12-man space station. Aviation week & space technology, v. 112, June 16, 1980: 26-29.
Soviet development of a powerful thrust booster and a 220,000-lb. military/scientific space station will provide the USSR with a base to launch the first manned mission to Mars, as well as a strategic advantage over the U.S.

Dondi, G. Space activities in the 80's: the programs and the industry. Parts 1 and 2: survey of space programs (1975 to 1980); survey of the capabilities and experience of the European Space Agency. Paris, European Space Agency. 1981. 290 p.
"ESA-SP-1012-V-L-1"
Reviews programs of the European Space Agency and summarizes European industrial participation in space programs. Provides information on manufacturers in ESA countries involved in space industries.

Kinnucan, Paul. Rocket wars: how Europe may zap America. High technology, v. 3, Apr. 1983: 49-56.
"Europe's success in wooing space launch customers from NASA may embolden other competitors."

Lenorovitz, Jeffrey M. Arianespace markets launch service. Aviation week & space technology, v. 116, Jan. 11, 1982: 87, 90-91, 93, 95.
"Successful entry of Europe's Ariane launch vehicle into worldwide satellite launch services competition has been aided by the private Arianespace organization, which was formed to sell the system to prospective payload customers."

Oberg, James E. Made in the USSR: Kosmograd space colony number one? Space world, v. R-4-208, Apr. 1981: 4-13.
The author contends that "throughout the 1980s, Soviet space stations will grow in size, beyond the intermediate ones holding two to six crewmen. . . . Space experts are even predicting the appearance of 'space towns' with several thousand people, perhaps by the end of the century."

----- Soviet developments point for space operations center. Aeronautics & astronautics, v. 20, May 1982: 74-77.
Claims that "spacecraft systems already demonstrated will allow Soviet space engineers to create a permanently manned station in the near future."

[Salyut] Space world, v. p-4-184, Apr. 1979: 4-34.
Special issue on the Russian Salyut manned space program. The articles cover the history of the program, the international cooperative aspects, military Salyuts, and medical-biological aspects of the program.

Scott, William F., and Harriet Fast Scott. Space: are the Soviets ahead? Air Force magazine, v. 64, Mar. 1981: 84-89.
Recount the Soviet manned space program from Yuri Gagarin's flight in April, 1961 to the present.

Smith, Marcia S. Soviet space activities: impact on U.S. space policy. Space world, v. S-4-202, Apr. 1982: 19-21, 23, 34.
Reviews current Soviet space activities and considers how they might impact on U.S. space policy.

Soviet astronautics. Journal of the British Interplanetary Society, v. 36, Oct. 1983: whole issue.
Contents.--The evolution of the Soyuz programme, by P. Clark.--Salyut mission report, by N. Kidger.--Soviet space science, by J. Powell.--Soviet nuclear powered satellites, by R. Rees and C. Vick.--Soviet manned space flight hardware, by D. Haeseler.--The Soviet cosmonaut team, 1960-1971, by R. Hall.--The Soviet cosmonaut team, 1971-1983, by R. Hall.

Spacelab. Journal of the British Interplanetary Society, v. 29, Nov. 1976: whole issue.
Special issue on Spacelab, the European space station to be launched by the NASA Space Shuttle. Articles cover technical details, missions planning, and the nature of the cooperation necessary to design and launch this joint U.S.-European space program.

U.S. Central Intelligence Agency. National Foreign Assessment Center. Ariane: a European space launch vehicle. Washington [Available from NTIS] 1980. 13 p.
"SW80-10074, Oct. 1980"
Discusses characteristics and capabilities of the Ariane launch vehicle.

U.S. Congress. Office of Technology Assessment. Salyut: Soviet steps toward permanent human presence in space--a technical memorandum. Washington, OTA, for sale by the Supt. of Docs., G.P.O., 1983. 69 p.
"OTA-TM-STI-14, Dec. 1983"
Partial contents.--Early Soviet manned spaceflight.--Pre-Salyut Soyuz space flights.--Salyut space station characteristics.--Salyut activities.--Future directions.--Impact on foreign policy.

Winick, Lester E. Birth of the Russian space programme. Spaceflight, v. 20, May 1978: 162-173.
"This paper summarises the principal organisations, past and present, which have been concerned with the development of rocketry and cosmonautics" in the Soviet Union.

IV. MILITARIZATION OF SPACE

Anti-satellite weapons: arms control or arms race? Cambridge, Mass., Union of Concerned Scientists, 1983. 44 p.

Contents.--Current U.S. and Soviet space assets and ASAT systems.--A treaty limiting ASAT weapons.--The relationship between ASAT and ABM.--The ASAT threat with and without a treaty.--Verification and residual risks.--Comparison with the 1981 Soviet draft treaty.

The Arms control reporter: a chronicle of treaties, negotiations, proposals. 1982- Brookline, Mass., Institute for Defense & Disarmament Studies. monthly.

See section on Anti-Satellite Talks and space weapons update.

Bell, Trudy E. America's other space program. Space world, v. Q-4-196, Apr. 1980: 4-12.

Reports on developments in the military space program, which is seen as the "other" space program as distinct from NASA's efforts. Considers the investment in space exploration and defense to be too important to be curtailed by budgetary considerations.

Broad, William J. A fatal flaw in the concept of space war. Science, v. 215, Mar. 1982: 1372-1374.

The author states that "the exotic weaponry on which the Pentagon now spends more than $300 million a year would be rendered useless by a single nuclear blast in outer space."

Brown, Harold, Bernard Feld, Robert Jastrow, and Richard Garwin. The Space Shuttle and defense. New York, WNET/Thirteen, 1981. 8 p.

The MacNeil/Lehrer Report, Apr. 13, 1981.

Televised interview with "Harold Brown, former Defense Secretary; Bernard Feld, physicist; Robert Jastrow, NASA; Richard Garwin, physicist."

The military possibilities of the Space Shuttle are discussed in this interview.

Burbidge, E. Margaret. Adventure into space. Science, v. 221, July 29, 1983: 421-427.

Extols the benefits of space exploration but notes that "technological advances have given us the capability of extinguishing life on Earth in a nuclear holocaust."

Conference on the United Nations of the Next Decade, 17th, Cooperstown, N.Y., 1982. Maintaining peace in outer space. Muscatine, Iowa, Stanley Foundation, 1982. 48 p.

This conference discussed international cooperation for peaceful uses of space, preventing weaponization of space, and the future role of the United Nations in space management.

Giffen, Robert B. US space system survivability: strategic alternatives for the 1990s. Washington, National Defense University Press, 1982. 68 p. (National Defense University. Monograph series, no. 82-4)

Contents.--Why survivability?--The basics.--US and Soviet space systems: a satellite gap?--How to defeat a space system.--Meeting the threat.--Matching survivability to requirements.

Goedhuis, D. Some observations on the efforts to prevent a military escalation in outer space. Journal of space law, v. 10, spring 1982: 13-30.

Concludes that the chances of reaching a universal agreement on arms limitation in space will depend on a more widespread public consciousness of the need to reach such an agreement.

Graham, Daniel O. Defense and development on the high frontier. Imprimis, v. 11, June 1982: 1-6.
In this presentation, General Graham lists nine requirements the U.S. should meet to "reverse the ominous trends in the military balance if we adhere to current strategy and try to compete with the Soviets in piling up weapons of current technology."

----- High Frontier: a new national strategy. [Washington, High Frontier, 1982] 175 p.
Contents.--Strategy.--The military dimension.--Nonmilitary dimension.--Collateral actions.--Urgent requirements and costs.--Impacts.--Implementation.--Treaty considerations.

Hafner, Donald L. Averting a Brobdingnagian skeet shoot. International security, v. 5, winter 1980-1981: 41-60.
The author reviews the issues at stake and suggests what an effective anti-satellite (ASAT) agreement should contain.

Haggerty, James J. Military in space. Aerospace, v. 20, spring 1982: 1-9.
Highlights DOD research and development activities in space which are aimed at matching Soviet military capabilities in space.

Jastrow, Robert. The new Soviet arms buildup in space. New York times magazine, Oct. 3, 1982: 30-34, 89, 92-93, 98, 100.
"Russian leaders have long recognized the potential of space as a military arena. But only in recent years have they begun to develop a massive military space capability. A prominent space scientist warns that by developing satellites that can carry nuclear bombs, 'killer satellites' and other weapons, the Kremlin has forged ahead in the military use of space."

Kane, Francis X. Anti-satellite systems and U.S. options. Strategic review, v. 10, winter 1982: 56-64.
Reviews Soviet development of antisatellite systems (ASAT), examines Soviet ASAT objectives, and considers the implications for U.S. security.

Kaplan, Daniel. Lasers for missile defense. Bulletin of the atomic scientists, v. 39, May 1983: 5-8.
The author argues that the idea of using lasers in space to defeat a nuclear attack is flawed. To be effective, a sufficient number of lasers able to shoot down all Soviet missiles would need to be over the Soviet Union at all times. The author warns that the deployment of lasers could create instabilities in the strategic balance between the United States and the Soviet Union.

Karas, Thomas H. The new high ground: systems and weapons of space and war. New York, Simon and Schuster, 1983. 224 p.
The author calls for a national debate on the direction of our space policy before the U.S. becomes committed to a new arms race in space.

Koppes, Clayton R. The militarization of the American space program: an historical perspective. Virginia quarterly review, v. 60, no. 1, winter 1984: 1-20.
Warns that the 1980's may become the decade of American military exploitation of space. Criticizes the Reagan administration for shifting resources from the civilian and scientific side of the space program to the military.

Lacouture, John E. Space race. United States Naval Institute proceedings, v. 109, Feb. 1983: 51-57.
"The U.S. military has been slow to recognize the dangers of Soviet space supremacy to our national security. Although increasingly dependent on satellites for communications, surveillance, warning, weather, and navigation, development of military weapon systems in space has proceeded on a low-priority basis."

Lorenzini, Dino A. Space power doctrine. Air University review, v. 33, July-Aug. 1982: 16-21.
Recommends that the U.S. adopt a space power doctrine which is as comprehensive and unencumbered as possible. Describes elements of such a doctrine, and considers obstacles to its formulation.

Outer space--a new dimension of the arms race, edited by Bhupendra Jasani. London, Taylor & Francis; Cambridge, Mass., Distributed by Oelgeschlager, Gunn & Hain, 1982. 423 p.
Contains papers first presented at a symposium organized by the Stockholm International Peace Research Institute and held in Stockholm, November 17-20, 1981. This book is directed to the reader concerned about the extension of the arms race into outer space.

Putting America's defense into orbit: the most radical strategic policy change since World War II. Business week, no. 2795, June 20, 1983: 52-53, 56, 60.

Reagan, Ronald. National security: address to the nation, March 23, 1983. Weekly compilation of Presidential documents, v. 19, Mar. 28, 1983: 442-448.
Sometimes characterized as the "star wars" speech.

The Reality behind 'star warfare'. International currency review, v. 15, July 1983: 36-42.
"Expenditure on space warfare is going to exert additional open-ended pressures on the dollar financial system through opening a further dimension of headlong deficit-spending, which the collective ingenuity of the Federal bureaucy will be unable to offset or disguise."

Ritchie, David. Laser-rattling in outer space. Inquiry (San Francisco), v. 3, Sept. 1, 1980: 13-17.
The article deals with the arms race in space between the United States and the Soviet Union, and its implication for world peace due to the lack of an adequate treaty to limit space warfare.

Robinson, George S. Militarization and the Outer Space Treaty--time for a restatement of "space law". Astronautics & aeronautics, v. 16, Feb. 1978: 26-29.
"For outer space to be a sanctuary from the ever-grinding conflicts on Earth, resolve and teeth should be put into this multinational accord Outer Space Treaty."

Smith, Bruce A. Military space system applications increasing. Aviation week & space technology, v. 114, Mar. 9, 1981: 83-87.
Examines the increased utilization of space-based systems for military purposes, and views this as a strong trend during the 1980s.

Smith, Marcia S. The militarization of space and other international space issues. Congressional Research Service review, v. 3, Nov. 1982: 5-7, 18.
Reports on the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, held in Vienna in August 1982.

----- Soviet space activities: impact on U.S. space policy. Space world, v. S-4-220, Apr. 1982: 19-21, 23, 34.
Reviews current Soviet space activities, and considers how they might impact on U.S. space policy.

Smith, R. Jeffrey. Administration resists demands for ASAT ban. Science, v. 222, Oct. 28, 1983: 394-396.
Presents Soviet and American attitudes toward a ban on antisatellites.

----- Antisatellite weapon sets dangerous course. Science, v. 222, Oct. 14, 1983: 140-142.
Warns that "if the real goal is to destroy the sensors that would warn the Soviets of a U.S. attack, the ASAT [antisatellite] has the potential to disrupt the present formulation of deterrence; continued ASAT development therefore seems likely to launch the country on a highly uncertain strategic course."

Soviet space operations emphasize strategic role. Defense electronics, v. 15, Oct. 1983: 140, 145-147.
"In the Soviets' quest for military supremacy, the U.S. is facing a frightening array of advanced satellites with a variety of military missions--and Russian spaceborne weapons platforms and a shuttlecraft are expected soon."

Space weapons. Bulletin of the atomic scientists, v. 40, May 1984: 15-15S.
Contents.--History and current debate, by R. Garwin and J. Pike.--Effect on strategic stability, by Y. Velikov.

Space weapons policy. Congressional digest, v. 63, Mar. 1984: 67-96.

Stares, Paul. Space and US national security. Journal of strategic studies, v. 6, Dec. 1983: 31-48.
"This article provides an overview of the evolution of the US military space program to illustrate the importance of outer space to US national security. Particular attention will be paid to the formulation of US space policy, the organization and management of the space program, the development of key satellite programs and the salient operational trends that have characterized the US militarization of space."

Stashevsky, Sergei, and Gennadi Stakh. Outer space must be free from weapons. Social sciences, v. 14, no. 2, 1983: 189-198.
"The rapid development of space technology has made the task of preventing the spread of the arms race to outer space an urgent and primary one."

Tsipis, Kosta, and Eric Raiten. Antisatellite weapons: the present danger. Technology review, v. 87, Aug.-Sept. 1984: 54-63.
Describes Soviet and American antisatellite development. Contends that "neither power could use the present generation of ASATS to prevent its opponent from launching a first strike or retaliating against cities and industry. This means that neither nation could alter the outcome of a nuclear attack or the general strategic balance." Calls for a treaty that would allow the present generation of ASATS but outlaw further developments.

U.S. Congress. House. Committee on Appropriations. Subcommittee on the Dept. of Defense. Department of Defense appropriations for 1984. Hearings, 98th Congress, 1st session. Washington, G.P.O., 1983. 818 p.
Part 8--Air Force procurement programs (except MX and B-1B); MX missile program; Command, control and communications programs; Role of military in space; Procurement policies and practices.

U.S. Congress. Office of Technology Assessment. Arms control in space: workshop proceedings. Washington, O.T.A., for sale by the Supt. of Docs., G.P.O., 1984. 64 p.
The workshop explored the relevance of anti-satellite (ASAT) weapons and tactics to arms control. Participants in the workshop stressed that "ASAT arms control cannot be a substitute for protecting and duplicating satellite functions."

----- Directed energy missile defense in space. Washington, O.T.A., for sale by the Supt. of Docs., G.P.O., 1984. 98 p.
Contents.--Booster characteristics.--Directed energy weapon concepts for boost phase intercept.--Other essential elements of a boost-phase intercept system.--Countermeasures to boost-phase intercept.--A word on "old" BMD and "new" BMD.--A hypothetical system architecture.--Defense goals I: the perfect defense.--Defensive goals II: less-than-perfect defense.--Principal judgments and observations.

U.S. Congress. Senate. Committee on Foreign Relations. Controlling space weapons. Hearings, 98th Congress, 1st session, on S. Res. 43 and S.J. Res. 28. Washington, G.P.O., 1983. 173 p.
Hearings held Apr. 14 and May 18, 1983.

U.S. General Accounting Office. U.S. antisatellite program needs a fresh look; report by the Comptroller General of the United States. Washington, G.A.O., 1983. 3 p.
"GAO/C-MASAD-83-5, Jan. 27, 1983"
"This is an unclassified digest furnished in lieu of a report containing security information."

U.S. President (1981- : Reagan) U.S. policy on ASAT Arms Control; communication from the President of the United States transmitting a report on his Administration's policy on arms control for antisatellite systems as required in the conference report for the Department of Defense Appropriations Act for fiscal year 1984. Washington, G.P.O., 1984. 24 p. (Document, House, 98th Congress, 2nd session, no. 98-197)

V. RESOURCE ALLOCATION AMONG COMPETING NATIONAL PRIORITIES

Brundage, Percival Flack. The Federal budget: recent trends and future opportunities. Price Waterhouse review, v. 15, autumn 1970: 6-21.
The former Director of the Budget makes some pertinent observations about the difficult national problems the OMB is currently dealing with--and those it will have to deal with in the years ahead.

The Dollars and logic of reordered priorities. Saturday review, v. 54, Oct. 9, 1971: 22-27, 54.
Contents.--Battling the balance sheet, by L. Ritter.--All the muscle at one-third the cost, by S. Melman.
Dr. Ritter's article appeared as "The political arithmetic of reordered national priorities" in the July 1971 Morgan Guaranty Survey.

Greenspan, Alan. "Fiscal constituencies"; they pose a mounting challenge to a free society. Barron's, v. 50, Oct. 12, 1970: 1, 8, 10, 12.
In a speech before the National Association of Business Economists, the author warns that "fiscal constituencies," i.e., individuals receiving payment in cash or in kind on a continuing basis under an ongoing Federal program, such as social security or Medicaid, pose a growing burden and a mounting challenge to a free society.

Humes, Kathryn H., and others. The future environment: U.S. and world trends. Washington, National Aeronautics and Space Administration 1975. 1 v. (various pagings)

"Aside from the Introduction, this volume is a collection of essays on some twenty issues that we have identified as reflecting a need for national policy-making and, a priori, having implications for spaceflight. Each essay contains a statement of the issue, a discussion of the dimensions of the problem, supporting information and data, and a list of potential policies or actions that might be taken."

Partial contents.--Non-renewable resources.--International conflict.--Population and food.--Environment.--Economics.--Individual and society.

Kamlet, Mark S., and David C. Mowery. The budgetary base in Federal resource allocation. American journal of political science, v. 24, Nov. 1980: 804-821.

"This paper examines the role of the budgetary base in the executive branch's federal budgetary process, focusing on the Office of Management and Budget (OMB). The analysis calls into question a number of standard assumptions in the theory of governmental budgetary decision-making. These include the definition of the base, its immutability over the planning cycle, the functions that it serves, and the extent to which it, as opposed to the increment, is the focus of attention of budgetary actors."

Lecht, Leonard A. Change in national priorities during the 1960s: their implications for 1980. [Washington] National Planning Association [c1972] 50 p. (National Planning Association. Report no. 132)

Says that if the trends of the 1960s continue, the U.S. may be overspending in defense and transportation and falling short of demands for increased welfare and urban expenditures by 1980.

Marshall, Ray. An effective alternative policy for the 1980's. USA today (magazine), v. 111, May 1983: 40-46.

"Our nation needs to target limited economic resources in a way that will assure healthy industrial development and full employment for the American economy of the 1980's and beyond."

Mayo, Robert P. The Federal experience viewed from the Executive Office of the President: an appraisal of our capabilities for meeting public needs. National tax journal, v. 25, Sept. 1972: 335-342.

Discusses two principal phases of the Federal Government resource allocation process: the year-long executive task of program examination, resource evaluation, and related tasks and the legislative task of examining, altering and authorizing specific programs, providing the obligational authority to incur expenditures and levying the taxes to pay for them.

National Tax Association Seminar on Financing the Seventies, Boston, 1972. Proceedings. National tax journal, v. 25, Sept. 1972: whole issue.

Contents.--Fiscal decision making: spending requirements and executive choice among competing expenditure categories--who gets what, when, and how much.--Legislative decision making: developing organization and procedures for high quality tax systems.--Possible new revenue sources for the seventies.--Developing changes in existing revenue sources.

National Urban Coalition. Counterbudget; a blueprint for changing national priorities 1971-1976. New York, Praeger [c1971] 348 p.

Okun, Arthur M. Equality and efficiency: the big tradeoff. Washington, Brookings Institution [c1975] 124 p.

Explores the conflicts that arise when society's desire to reduce inequality would impair economic efficiency, confronting policymakers with "the big tradeoff."

Public claims on U.S. output: Federal budget options in the last half of the seventies. Washington, American Enterprise Institute for Public Policy Research [1973] 218 p. (American Enterprise Institute for Public Policy Research. Domestic affairs studies, no. 18)

Study finds that the 1974 Federal budget program, if implemented, meets the administration's stated goal of a virtual balance between expenditures and "full employment" receipts in calendar year 1975 and would provide surpluses thereafter, rising from $9 billion in 1976 to $57 billion in 1980. The authors examine the rationale for existing programs and develop, in varying degrees of detail, the costs of other alternatives, asking such questions as: how well are existing programs in defense, agriculture, science, technology and industry, housing, education, manpower, health, and income security meeting their stated goals? What viable options exist to present (or proposed) programs, including curtailments or terminations?

Rolan, Robert G. Must we choose between men in space and mankind on Earth. Bioscience, v. 20, July 15, 1970: 797-806.

"This paper is an attempt, to determine whether the goals of manned space flight and environmental improvement on Earth are really competitive and mutually exclusive or are, in fact, similar in many major points."

Russell, Bertrand. Let's stay off the Moon. Wall Street journal, July 16, 1969: 16.

Lord Russell questions whether the conquest of the moon or space can "ameliorate our human lot."

"There are some who seem to imagine that space travel, will, of itself, lead to some cure for our terrestrial troubles. I cannot see any reason to think this. Europe had troubles before the Western Hemisphere was discovered. After it was discovered, the wars to which the old world was accustomed were transplanted to the 'new world.' Unless we amend our ways, the same thing will happen if we extend our silly empires into outer space."

Sederberg, Peter C., and Marcia Whicker Taylor. The political economy of no-growth. Policy studies journal, v. 9, spring 1981: 735-755.

"Problems of scarcity generate critical political issues as advanced industrial societies shift away from growth-oriented economies. This analysis recommends substituting more abundant political resources for scarce economic ones. Appropriate scenarios resulting from these substitution patterns are subjected to speculative analysis."

Setting national priorities: the 1984 budget. Washington, Brookings Institution, 1983. 248 p.

Contents.--Introduction and summary, by J. Pechman.--The budget and the economy, by J. Pechman.--The defense budget, by W. Kaufman.--Social security, by A. Munnell.--Medical care, by L. Russell.--Jobs and training, by D. Saks.--Tax policy, by H. Galper.--The choices ahead, by H. Aaron.--Appendix A. Estimates of the structural deficit, by J. Pechman.--Appendix B. Federal credit activities, by E. Rhyne.--Appendix C. Tax expenditures, by J. Scholz.

This report, analyzing the Federal budget, is the latest in a series dating back to 1970.

Space Shuttle: NASA versus domestic priorities. Congressional quarterly weekly report, v. 30, Feb. 26, 1972: 435-439.

Strengthening the Federal budget process: a requirement for effective fiscal control. Washington, Committee for Economic Development, Research and Policy Committee, 1983. 106 p.

Contents.--Introduction and summary of recommendations.--Budget concepts: improving the information base for budget decisions.--Budget processes: strengthening procedures for budget decisions and enforcement.--Next steps for improving the budget process.--Memoranda of comment, reservation, or dissent.

U.S. Congress. Joint Economic Committee. Subcommittee on Economy in Government. Changing national priorities. Hearings, 91st Congress, 2nd session. Washington, G.P.O., 1970. 2 v. (741 p.)
Hearings held June 1-18, 1970.

U.S. Domestic Council. White House public forums on domestic policy, 1975; report to the President. [Washington, 1976] 765 p.
Summarizes findings of the six forums held in Denver, Tampa, Fla., Austin, Tex., Philadelphia, Indianapolis, and Los Angeles during Oct.-Dec. 1975. Focus of the discussion is on economic growth, resource development, social policy and community building.

RESEARCH GUIDE

SPACE EXPLORATION AND DEVELOPMENT:

A GUIDE TO SOURCES OF INFORMATION

B. F. Mangan
Library Services Division

August 1984

RESEARCH SOURCES

This is a listing of research tools described in this guide, listing the pages where they are mentioned.

Aerospace Daily 6
Aerospace Daily Online 6
Applied Science & Technology Index 6
Arms Control Reporter 7
Bell & Howell Newspaper Indexes 5
Business Periodicals Index 2
CIS Index 4
Congressional Quarterly Weekly Report 3
Congressional Record 2
Congressional Record Abstract Files 3
Digest of Public General Bills and Resolutions 4
Encyclopedia of Associations 8
International Aerospace Abstracts 7
Library of Congress Computerized Catalog 1
Magazine Index 1
Major Legislation of the Congress 4
Monthly Catalog of United States Government Publications 5
National Journal 3
National Newspaper Index 6
Newssearch 6
New York Times Index 5
NEXIS 6
NTIS 7
Official Washington Post Index 6
Public Affairs Information Service Bulletin 2
Science Citation Index 7
Scientific and Technical Aerospace Reports (STAR) 7
Scisearch 7
Readers' Guide to Periodical Literature 2
Washington Information Directory 8
Weekly Compilation of Presidential Documents 5

[References to data bases commercially available would include such sources as DIALOG, ORBIT, NEXIS, and BRS.]

CONTENTS

PART I: BASIC REFERENCE SOURCES

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PART II: SPACE REFERENCE SOURCES

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INTRODUCTION

This research guide identifies research tools and sources of information about astronautics & space sciences. The guide is divided into two parts. The first part describes basic research sources and lists the search terms which can be used when examining these tools. The second part describes specialized space reference sources.

Users of this guide may be able to locate these materials at a nearby public, research, or depository library. The Congressional Research Service cannot perform searches of the commercial online data bases or provide copies of the items listed.

BOOKS

Library of Congress subject headings are used in many library catalogs nationwide. This partial listing of subject headings may be used to identify books in the Library of Congress catalog and other library catalogs on space issues.

SEARCH TERMS:
- Artificial satellites
- Astronautics
- Astronautics and civilization
- Budget--United States
- Manned space flight
- Outer space--Exploration
- Space law
- Space stations
- United States--Economic policy
- United States--Social policy

The search terms listed above may also be used for online commercial access to Library of Congress bibliographic records.

JOURNAL ARTICLES

Citations to journal articles and other materials about space can be found in a number of printed indexes and online bibliographic data bases. The materials covered by the printed indexes are briefly described here and the appropriate search terms are also listed.

Online bibliographic data bases enable the researcher to locate citations to journal articles and other materials quickly by using a computer terminal to search a machine-readable file. Online data bases allow the researcher to combine search terms in ways that are impossible in a printed index or library catalog and to simultaneously search material that would be contained in printed index volumes covering several years. The availability of various indexes online is indicated in the description of the tools.

> MAGAZINE INDEX

Magazine Index provides citations to materials in over 370 popular magazines, focusing on coverage of current affairs, leisure time activities, arts, sports, and science and technology. The Index is available online commercially.

SEARCH TERMS:
- Artificial satellites
- Astronautical research
- Astronautics
- Astronautics and state
- Budget--planning
- Space colonies
- Space flight
- Space sciences
- Space shuttles
- Space weapons

> PUBLIC AFFAIRS INFORMATION SERVICE BULLETIN (PAIS)

PAIS is a subject index of books, pamphlets, government publications, reports of public and private agencies, and periodical articles relating to economic and social conditions, public administration, and international relations. PAIS is available online commercially.

SEARCH TERMS:
- Budget, Government
- Satellites, Artificial
- Space flight
- Space, outer
- Space research
- Space stations
- Space technology
- United States--Economic policy
- United States--Social policy

> READERS' GUIDE TO PERIODICAL LITERATURE

The Readers' Guide is an author/subject index to periodicals of general interest published in the U.S.

SEARCH TERMS:
- Artificial satellites
- Budget
- Space colonies
- Space flight
- Space research

> BUSINESS PERIODICALS INDEX

Business Periodicals Index is a subject index to articles appearing in English language business periodicals. The Index is issued monthly and cumulated quarterly and annually.

SEARCH TERMS:
- Astronautics
- Budget
- Program budgeting
- Satellites, Artificial
- Space flight
- Space research
- Space vehicles

LEGISLATIVE INFORMATION

Congressional activities on space issues may be monitored by searching the following printed publications.

> CONGRESSIONAL RECORD

The Congressional Record provides an edited transcript of the activities on the floor of the House and the Senate. It is published each day Congress is in session. Subject and name indexes are published biweekly and cumulated annually.

SEARCH TERMS:
- Budget of the United States
- National Aeronautics and Space Administration
- Space policy
- Space program
- Space sciences

> CONGRESSIONAL RECORD ABSTRACT FILES

The Congressional Record Abstract Files (CR) contain abstracts of material in the Congressional Record from the 94th Congress, 2d session to the present. A typical entry includes the abstract, bill numbers, indexing terms, and page number references to the full text of the Congressional Record, and the date of the Record. These files have full-text retrieval capabilities, making it possible for the researcher to formulate his own search terms in addition to using terms which are part of a controlled searching vocabulary. The CR files are commercially available to the general public.

SEARCH TERMS:
Artificial satellites
Astronautics
Space law
Space policy
Space sciences

Bills and Resolutions

> CONGRESSIONAL QUARTERLY WEEKLY REPORT

Congressional Quarterly Weekly Report provides current information on congressional activities, the progress of major bills, and background information on major policy issues. Important recent articles are indexed on the back cover of each issue. Consult this index under the heading "Budget" and "Defense." A quarterly and an annual index are also issued. Congressional Quarterly also publishes an annual publication which cumulates material appearing in the weekly reports during a year. This publication is entitled CQ Almanac. Congressional Quarterly Weekly Report is available online through the NEXIS library.

SEARCH TERMS:
Appropriations
Budget
Defense
Foreign policy

> CONGRESSIONAL QUARTERLY ALMANAC

See description above.

SEARCH TERMS:
Budget, U.S.
Missiles [for ASAT]
National Aeronautics and Space Administration
Satellites
Space and space programs
Space policy

> NATIONAL JOURNAL

National Journal provides information on important executive branch and congressional actions. In addition to the annual index, the back cover of each issue also contains a brief index to recent articles. Consult this index under the headings "Defense" and "Budget."

SEARCH TERMS:
Economy, domestic
National Aeronautics and Space Administration

> DIGEST OF PUBLIC GENERAL BILLS AND RESOLUTIONS

The Digest summarizes the essential features of public bills and resolutions and changes made in them during the legislative process. The Digest is published during each session of Congress in two cumulative issues and a final issue at the conclusion subject indexes.

SEARCH TERMS:
Economic policies and conditions
Public finance and budgets
Space
- Artificial satellites
- Communication satellites
- Space policy

> MAJOR LEGISLATION OF THE CONGRESS (MLC)

The MLC provides summaries of selected major legislation arranged by subject. It includes background on the issues and information on the content and status of major bills affecting that issue. The publication may be examined at a Government depository library or purchased from the Government Printing Office. Search under the headings "Space issues" in the table of contents.

SEARCH TERMS:
Budget and government spending
National defense and security
Science and technology

Congressional Publications

> CIS INDEX (Index to the Publications of the United States Congress)

The CIS Index, produced by the Congressional Information Service, abstracts all congressional publications with the exception of the Congressional Record. The Index is published monthly and cumulated quarterly and annually. Each issue of the Index is divided into index and abstract portions. The Index is commercially available online.

SEARCH TERMS:
Astronautics
Budget of the U.S.
Communication satellites
International cooperation in astronautics
Space commercialization
Space programs
Space research
Space shuttle
Space stations
Space weapons

Copies of recently issued hearings and committee prints should be requested directly from the issuing committee. Congressional hearings and committee prints may also be found in the collections of Government depository libraries.

GOVERNMENT PUBLICATIONS

> MONTHLY CATALOG OF UNITED STATES GOVERNMENT PUBLICATIONS

The Monthly Catalog lists documents issued by all branches of the Federal Government. The catalog has monthly, semiannual, and annual indexes arranged by author, title, subject, keywords, and series/report title. The Monthly Catalog is commercially available online.

SEARCH TERMS:
Headings starting with the word Astronautics
Headings starting with the words Artificial satellites
Headings starting with the word Budget
Headings starting with the word Space

> WEEKLY COMPILATION OF PRESIDENTIAL DOCUMENTS

The Weekly Compilation of Presidential Documents contains statements, messages, and other presidential materials released by the White House during the preceding week. The Weekly Compilation has weekly, quarterly, and annual indexes.

SEARCH TERMS:
Arms and munitions
- Outer-space weapons
Budget, Federal
Space program

NEWSPAPER ARTICLES

The following indexes may be used to locate newspaper articles on space issues.

> NEW YORK TIMES INDEX

The New York Times Index provides extensive abstracts for articles appearing in the New York Times.

SEARCH TERMS:
Astronautics
Budgets and budgeting
Satellites
Space
Space weapons
United States--Finances--Budgets and budgeting

> BELL & HOWELL NEWSPAPER INDEXES

The Bell & Howell Newspaper Indexes list articles appearing in the Chicago Tribune, Chicago Sun-Times, Denver Post, Detroit News, Houston Post, Los Angeles Times, New Orleans Times-Picayune, San Francisco Chronicle, and Washington Post.

SEARCH TERMS:
Artificial satellites
Space (Outer)
Space exploration
Space stations
Space vehicles
United States Govt.--Budget

> OFFICIAL WASHINGTON POST INDEX

The Index provides access to all substantial newsworthy items in this paper.

SEARCH TERMS:
Artificial satellites
Astronautics
Budget--United States
Reusable space vehicles
Space ships
Space stations

> NATIONAL NEWSPAPER INDEX

National Newspaper Index, produced by Information Access Corporation, is available online as part of the Lockheed Dialog system, and provides front-page to back-page indexing on current affairs topics in the Christian Science Monitor, New York Times, Wall Street Journal, Los Angeles Times, and the Washington Post.

> NEXIS

The NEXIS online library provides access to wire service articles from the Associated Press, United Press International, and Reuters, articles from the Washington Post and journal articles. The journals indexed include Newsweek and U.S. News & World Report. In addition to providing citations and abstracts of the materials included in the data base, NEXIS makes the full text of the articles available online. NEXIS also provides access to the New York Times Information Bank, which is a current affairs data base containing citations to the New York Times and over sixty newspapers and journals.

> NEWSSEARCH

Newssearch is the daily update of Magazine Index, National Newspaper Index, and Legal Resources Index in the Lockheed Dialog system. It provides front-page to back-page indexing of the Christian Science Monitor, Wall Street Journal, and New York Times, as well as popular magazines, law journals, and legal newspapers.

ADDITIONAL SOURCES OF SPACE INFORMATION

INDEXES AND BIBLIOGRAPHIC DATA BASES

Citations to journal articles and other materials about space issues will be found in a number of printed indexes and online bibliographic data bases.

Aerospace Daily On-Line is a commercial database available from Ziff-Davis Publishing Company, 1156 15th St. N.W., Washington, D.C. 20005. It contains the same information as Aerospace Daily and can be used to search for defense and space programs, budgets, and technical and industrial trends. The system has two sections: Aerospace Daily abstract service which has daily on-line delivery of 2-3 line abstracts and full text call-up capabilities; and Aerospace Intelligence Retrieval which includes Aerospace Daily Historical Service, Defense Budget Scan, NASA Budgetscan and Defense Electronics Magazine.

Applied Science & Technology Index is a subject index to articles appearing in science and engineering journals. The Index is issued monthly and cumulated quarterly and annually.

Arms Control Reporter is a published monthly by the Institute for Defense and Disarmament Studies. The Reporter presents the status, analysis and chronology on treaty negotiations on such topics as Anti-ballistic Missile Treaty, SALT II, chemical weapons, antisatellite talks and nuclear non-proliferation. The chronology pages give day-to-day coverage of talks compiled from news services around the world. The parties, agendas and positions of all sides involved in the talks are included in the status pages. Text pages reproduce the essential documents, communiques and speeches. In the analysis pages are outside critiques of the talks assembled from other publications. This section highlights how problems existing in treaty negotiations might be resolved.

International Aerospace Abstracts is published semimonthly by the American Institute of Aeronautics and Astronautics. IAA covers published literature in periodicals and books; meeting papers and conference proceedings issued by professional and academic organizations; and translations of journals and articles in aeronautics and space science and technology. Indexes are cumulated semiannually and annually.

NTIS (National Technical Information Service) database is available commercially online. NTIS consists of government sponsored research, development, and engineering prepared By Federal agencies, their contractors or grantees. Through this system, unclassified, publicly available reports are made available for sale from such agencies as NASA, DOE, DDC, HHS, HUD, DOT, and the Department of Commerce. The database includes materials from both the hard and soft sciences, including material on technological applications, business procedures and regulatory matters.

Science Citation Index is published quarterly with an annual cumulation. The Index provides access to related articles by indicating sources in which a known article by a given author has been cited. This index is available commercially online as Scisearch.

Scientific and Technical Aerospace Reports (STAR) is published by NASA on the 8th and 23rd of every month. Cumulative index volumes are published annually. STAR announces current publications on all aspects of aeronautics and space research and development, supporting basic and applied research, and applications. Included in STAR are NASA contractor, and NASA grantee reports, reports by U.S. Government agencies, domestic and foreign institutions, NASA owned patents and patent applications, and dissertations and theses.

REFERENCE BOOKS

The Illustrated encyclopedia of Space technology: a comprehensive history of space exploration. New York, Harmony Books, 1981. 289 p.

Traces the history of the conquest of space, and considers such concepts as space colonies, factories in space, satellite solar power stations and bases on the Moon. Contains information on Soviet and Chinese launch vehicles.

The McGraw-Hill encyclopedia of space. New York, McGraw-Hill, 1968. 381 p.

This work is a translation of La grande aventure de l'espace (Paris, 1967). Topical sections deal with rockets, artificial satellites, space navigation, man in space, life in the universe, astronomy-astrophysics, and astronautics in the world today.

The RAE table of earth satellites 1957-1982, 2nd edition, compiled at the Royal Aircraft Establishment, Farnborough, Hants, England. London, MacMillan Publishers, 1983. 753 p.

The Table is a chronological list of the 2,389 launches of satellites and space vehicles between 1975 and the end of 1982, giving the name and international designation of each satellite and its associated rockets, date of launch, lifetime, mass, shape, dimensions and at least one set of orbital parameters.

CRS-8

A Record of NASA space missions since 1958. Compiled by Alfred Rosenthal for the Goddard Space Flight Center. Washington, NASA Goddard Space Flight, 1982. 879 p.

Describes major NASA missions during the period of 1958 to 1981. Included are those in support of the U.S. space program, as well as projects conducted in cooperation with private industry and in association with foreign nations. The material is arranged chronologically.

ORGANIZATIONS

The following organizations were selected from the Encyclopedia of Associations and the Washington Information Directory, 1982-83 as possible sources of information on space issues. The descriptions of the groups' activities are taken from these sources.

Aerospace Industries Association of America
1725 DeSales St., N.W.
Washington, D.C. 20036
(202) 429-4600

This is an association of U.S. companies engaged in research, development, and manufacture of aerospace systems, including manned and unmanned aircraft; missiles; launch vehicles and spacecraft; and propulsion, guidance, and control units. Maintains a library which is open to the public.

American Institute of Aeronautics and Astronautics (AIAA)
1633 Broadway
New York, N.Y. 10019
(212) 581-4300

Includes scientists and engineers in the fields of aeronautics and astronautics. Conducts an interchange of technical information through its publications and technical meetings. Its Technical Information Service provides library and abstracting services including the semimonthly International Aerospace Abstracts.

American Astronautical Society (AAS)
6060 Duke St.
Alexander, Va. 22304
(703) 751-7721

Promotes and supports scientific research related to the development of astronautical sciences. Conducts an annual Goddard Memorial and Military Space Symposium.

Aviation/Space Writers Association
1725 K St., N.W.
Washington, D.C. 20006
(202) 296-4394

Provides information to members on the aviation and space industries; sponsors an annual news conference and regional meetings.

National Space Club (NSC)
655 15th St., N.W., No. 300
Washington, D.C. 20005
(202) 639-4210

This nontechnical organization of individuals and companies affiliated with the missile and space fields seeks to maintain U.S. space leadership, and stimulate the advancement of peaceful and military applications of space flight and related technologies. Its membership is drawn from government, industry, the military, and the press.

National Space Institute (NSI)
600 Mayland Ave., S.W.
West Wing, Suite 203
Washington, D.C. 20024
(202) 484-1111

Seeks to provide a forum for public participation to help ensure that the space program is responsive to public priorities. Provides information on NASA activities and promotes the space program nationally. Monitors legislation and regulations that affect the space program.

SELECTED PERIODICALS

The following periodicals frequently contain articles on space policy and protection issues:

Aerospace (Quarterly)
Aerospace Daily (5 times a week)
(a news service for the entire aerospace industry)
Air University Review (bimonthly)
Astronautics & aeronautics (monthly)
Aviation week & space technology (weekly)
Journal of space law (semi-annual)
Journal of the British Interplantary Society (monthly)
Spaceflight (monthly)
Science (weekly)

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SB-176
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Resolved: That the United States Federal Government Should Significantly Increase the Exploration and/or Development of Space Beyond the Earth's Mesosphere.

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Advanced Automation for Space Missions. *The final report of the study on the feasibility of using machine intelligence, including automation and robotics, in future space missions.* 1982. 394 p. il.
NAS 1.55:2255 S/N 033-000-00863-5 $ 9.50

Aeronautics and Space Report of the President, 1981 Activities. *Contains reports from NASA and other Federal departments concerning advances in space technology and applications.* 1982. 91 p. il.
NAS 1.52:981 S/N 033-000-00860-1 5.50

Aerospace Bibliography. *An annotated and graded list of books and reference materials dealing with aerospace subjects, published between 1971 and 1980.* Rev. 1982. 140 p. NAS 1.19:48/4 S/N 033-000-00866-0 6.00

Civilian Space Policy and Applications. *Evaluates the present state and possible future directions of space applications technologies in the civilian sector in the areas of satellite communications, land remote sensing, materials processing in space, and space transportation.* 1982. 401 p. il.
Y 3.T 22/2:2 C 49 S/N 052-003-00878-5 9.50

Directed Energy Missile Defense in Space, Background Paper. *Describes and assesses current concepts for directed-energy ballistic missile defense in space. Provides an introduction to the "Star Wars" technologies that may form the basis of defense against Soviet nuclear ballistic missiles.* 1984. 98 p. il.
Y 3.T 22/2:2 En 2/11
S/N 052-003-00948-0 4.50

Exploration of the Solar System. *Emphasizes the achievements and contributions from space explorations.* 1974. 67 p. il.
NAS 1.19:122 S/N 033-000-00581-4 4.75

Extragalactic Astronomy: The Universe Beyond Our Galaxy. 1976. 38 p. il.
NAS 1.19:129 S/N 033-000-00657-8 4.75

Forecast of Space Technology, 1980-2000. 1976, reprinted 1978. 385 p. il.
NAS 1.21:387 S/N 033-000-00641-1 8.50

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High Energy Astronomy Observatory. *Describes the HEAO 2 satellite and the unusual objects it studies, including black holes, supernova remnants, young stars, galaxies, and quasars.* 1980. 36 p. il.
NAS 1.19:167 S/N 033-000-00808-2 $ 3.50

Life Beyond Earth and the Mind of Man, A Symposium Held at Boston University, November 20, 1972. 1973, reprinted 1979. 106 p. il.
NAS 1.21:328 S/N 033-000-00518-1 4.75

Meeting With the Universe: Science Discoveries From the Space Program. 1981. 231 p. il.
NAS 1.19:177 S/N 033-000-00836-8 14.00

NASA Activities. (Monthly.) *Contains general and scheduled activities of NASA.* Subscription price: Domestic - $23.00 a year; Foreign - $28.75 a year. Single copy price: Domestic - $2.00 a copy; Foreign - $2.50 a copy. [NACT] (File Code 2M)
NAS 1.46: S/N 033-000-80002-9

NASA Aeronautics. Rev. 1980. 27 p. il.
NAS 1.2:Ae 8/5 S/N 033-000-00796-5 2.50

NASA Grant and Cooperative Agreement Handbook (NHB 5800.1A). *This Handbook prescribes policies and regulations relating to the award and administration of NASA research grants. It represents a significant NASA step in the publication and dissemination of NASA policies and procedures. Subscription service consists of a basic manual, changes and procurement grant directives issued irregularly for an indeterminate period.* October 1983. Subscription price: Domestic - $23.00; Foreign - $28.75. [NGH] (File Code 1X)
NAS 1.18:G 76/2/983 S/N 033-000-81001-6

NASA 1958-1983: Remembered Images. *A pictorial history of the National Aeronautics and Space Administration. Topics covered include the Space Shuttle, the Apollo Program, Apollo-Soyus, Voyager and Mariner spacecraft and the Spacelab.* 1983. 136 p. il.
NAS 1.19:200 S/N 033-000-00901-1 22.00

National Aeronautics and Space Administration, Twenty-Fifth Anniversary: 1958-1983. *A pictorial chronology of the National Aeronautics and Space Administration, beginning with the launching of Explorer One and continuing through the flight of Space Shuttle Challenger. This publication may be purchased at a special price of $24.00 per 100 copies when mailed to one address.* 1983. 13 p. il.
NAS 1.2:An 7 S/N 033-000-00879-1 2.75

National Space Program: From the Fifties Into the Eighties. *Traces the history of the National Space program from the 1950s to the present. Civilian and unclassified military space policies are analyzed. Programs of the National Aeronautics and Space Administration as well as the Department of Defense are included.* 1983. 130 p. il.
D 5.409:83-6 S/N 008-020-00959-8 4.25

Next Step: Large Space Structures. *Describes large antennas, space platforms, and other potential large space structures made possible by the Space Shuttle's capabilities.* 1982. 8 p. il.
NAS 1.20:NF-129 S/N 033-000-00853-8 2.00

New Dimension in Space Experimentation. *Explains in detail the uses of the Long Duration Exposure Facility (LDEF). There are 53 scientific and technological experiments inside the LDEF. It will use about 50% of the Space Shuttle's payload capacity and will be launched and retrieved by the Space Shuttle.* 1984. 12 p. il. NAS 1.20:NF-140 S/N 033-000-00914-3 $ 1.00

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Outlook for Space: Report to the NASA Administrator by the Outlook for Space Study Group. 1976. 385 p. il. NAS 1.21:386 S/N 033-000-00640-3 8.00

Planetary Exploration Through the Year 2000: Core Program. *Topics include recommended program strategy, the era of spacecraft exploration, scientific strategy for planetary exploration, core program implementation, and missions for a core program.* 1983. 167 p. il. NAS 1.2:Ex 7/2 S/N 033-000-00882-1 7.00

Executive Summary to the above. 1983. 28 p. il. NAS 1.2:Ex 7/2/exec.sum. S/N 033-000-00871-6 5.50

Possibility of Intelligent Life Elsewhere in the Universe, Report (Revised October 1977). Rev. 1977. 126 p. il. Y 4.Sci 2:95/0 S/N 052-070-04332-6 4.75

President's Private Sector Survey on Cost Control: Report on Research and Development. *Contains major recommendations which could result in cost savings for Federal research laboratories; administration of research grants to universities; NASA cost reporting; and in other aspects of Federal research and development.* 1984. 156 p. Pr 40.8:C 82/R 31 S/N 003-000-00625-5 4.50

Project Orion: A Design Study of a System for Detecting Extrasolar Planets. 1980. 204 p. il. NAS 1.21:436 S/N 033-000-00790-6 7.00

Proving the Space Transportation System: The Orbital Flight Test Program. *Describes a test program designed to verify the Space Shuttle Columbia's performance under real spaceflight conditions, and to establish its readiness for operational duty. Tests conducted included experiments with a mechanical arm, launching and landing systems, and various computer simulations.* 1983. 19 p. il. NAS 1.20:NF-137/83 S/N 033-000-00884-8 2.50

SALYUT: Soviet Steps Toward Permanent Human Presence in Space: A Technical Memorandum. 1983. 76 p. il., 8 photos in pocket. Y 3.T 22/2:11 Sa 3 S/N 052-003-00937-4 4.50

Scientific and Technical Aerospace Reports (STAR). (Semimonthly.) *This subscription announces abstracts, and indexes reports issued by the National Aeronautics and Space Administration, as well as by other Government agencies, universities, industry, and research organizations both in the United States and abroad.* Subscription price: Domestic - $100.00 a year; Foreign - $125.00 a year. Single copy price: Domestic - $6.50 a copy; Foreign - $8.15 a copy. [STAR](File Code 2E) NAS 1.9/4: S/N 033-000-80004-5

Scientific Research With the Space Telescope. *Contains the proceedings of the International Astronomical Union Colloquium Number 54, cosponsored by COSPAR, and held at the Institute for Advanced Study, Princeton, New Jersey, August 8-11, 1979.* 1979. 327 p. il.
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Search for Extraterrestrial Intelligence, SETI. *Presents the findings of a series of workshops conducted by NASA's Ames Research Center on interstellar communication; extrasolar planetary detection; and the evolution of intelligent species and technological civilizations (cultural evolution).* 1977. 276 p. il.
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Shuttle Era. *Describes the Space Shuttle system, presents a mission profile, and explains why the Shuttle has ushered in a new era for America's space program.* Rev. 1981. 8 p. il.
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Soviet Space Programs: 1976-1980, Part 1, Supporting Vehicles and Launch Vehicles, Political Goals and Purposes, International Cooperation in Space, Administration, Resource Burden, Future Outlook. 1982. 461 p. il. Y 4.C 73/7:Sp 1/2/pt.1
S/N 052-070-05800-5 7.50

Space Activities of the United States, Soviet Union, and Other Launching Countries, Organizations: 1957-1981, Report. 1982. 145 p.
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Space Resources and Space Settlements. *Contains the technical papers from the 1977 Summer Study on Space Settlements and Industrialization Using Nonterrestrial Materials, held at NASA Ames Research Center.* 1979. 288 p. il. NAS 1.21:428 S/N 033-000-00765-5 9.00

Space Science Research in the United States, A Technical Memorandum. *Examines the direction and purpose of the United States space science program.* 1982. 58 p. il.
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Space Settlements, A Design Study. *Presents a picture of how people might permanently sustain life in space on a large scale.* 1977. 185 p. il.
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Space Shuttle at Work. *Handsomely illustrated in color and black-and-white, this publication describes the lay-out of the Shuttle, its capabilities, the way it is launched and landed, a typical week's work for the crew, and the plans and dreams that weekly, routine space transportation permit.* 1979. 76 p. il.
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Spacelab: An International Short-Stay Orbiting Laboratory. *Traces the historical and technological developments of a joint program between NASA and the European Space Agency (ESA) leading to the building of the Space Shuttle Columbia's spacelab.* 1983. 82 p. il.
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Spinoff, 1984. *An illustrated annual review of the space program.* 1984. 126 p. il.
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Star Splitters: The High Energy Astronomy Observatories. *Traces the history and development of NASA's High Energy Astronomy Observatory (HEAO) Program.* 1984. 191 p. il.
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UNISPACE '82: A Context for International Cooperation and Competition, A Technical Memorandum. *As a post-conference review of UNISPACE '82 (United Nation's Conference on the Exploration and Peaceful Uses of Outer Space), this publication examines how the United States might make better use of international fora to achieve its diplomatic, commercial, and technical ends in space technology.* 1983. 93 p. il.
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Voyager at Neptune and Triton: 1989. *Describes the Voyager project and its voyage to Neptune in September of 1989, where it will encounter Triton, Neptune's largest moon.* 1984. 12 p. il.
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